Draft Final
Comprehensive Risk Assessment Work Plan and Methodology

April 2004

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SW-A-004913

Notes to Reviewer

It was agreed at the March 8 Risk Assessment Work Group meeting that the Draft Final Comprehensive Risk Assessment (CRA) Work Plan and Methodology would be reviewed by the regulatory agencies on a two-tier basis. First, the specific elements of the CRA methodology will be reviewed for consistency with previous agreements. Overall approved of the methods will be provided so that work can begin immediately on the Data Adequacy Report, the accelerate action screen, and the CRA itself. Then the regulatory agencies will submit any text edit comments which will be incorporated into the Final CRA Work Plan and Methodology.

Maps in the current draft final version of the methodology are in 11inch by 17 inch format. In the final methodology, all maps will be in the larger D-size drawing format.

The human health toxicity table in Section 4 will be updated in the final methodology to the newer version that has already been reviewed by the regulatory agencies.

The updated human health preliminary remediation goal (PRG) Tables, resulting from the toxicity factor update, will be presented for review and then incorporated into Appendix A of the final methodology.

The ecological exposure factor, toxicity reference value and remaining ecological screening level tables will be presented for regulatory agency review and approval by April 23, and then will be incorporated into Appendix B of the final methodology.

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ACRONYMS

95UCL	upper confidence limit of the mean at a 95 percent level
AL	action level
ALF	Action Levels and Standards Framework for Surface Water, Ground Water, and Soils
AWQC	Ambient Water Quality Criteria
BAF	bioaccumulation factor
BDAC	Biological Dose Assessment Committee
BOA	Basic Ordering Agreement
BZ	Buffer Zone
CAD/ROD	Corrective Action Decision/Record of Decision
CAS	Chemical Abstract Service
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm^2	square centimeter
COC	contaminant of concern
CRA	Comprehensive Risk Assessment
CRAVE	Carcinogenic Risk Assessment Verification Endeavor
CRQL	contract-required quantitation limit
CSF	cancer slope factor
DAD	dermally absorbed dose
DAR	Data Adequacy Report
day/yr	days per year
DCF	dose conversion factor
DER	duplicate error ratio
DOE	U.S. Department of Energy
DQA	data quality assessment
DQO	data quality objective
DRI	daily reference intake
ECOC	ecological contaminant of concern
ECOI	ecological contaminant of interest
ECOPC	ecological contaminant of potential concern
Eco-SSL	ecological soil screening level
Eh	reduction-oxidation potential
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration

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ACRONYMS

ERA	ecological risk assessment
ESL	Ecological screening level
EU	exposure unit
g/kg	grams per kilogram
g/mg	grams per milligram
HASP	health and safety plan
HEAST	Health Effects Assessment Summary Tables
HHRA	human health risk assessment
HI	hazard index
HQ	hazard quotient
hr/day	hours per day
IA	Industrial Area
IASAP	Industrial Area Sampling and Analysis Plan
ICA	Institutional Control Area
ICRP	International Commission on Radiological Protection
IHSS	Individual Hazardous Substance Site
IRIS	Integrated Risk Information System
kg	kilogram
kg/m^3	kilograms per cubic meter
kg/mg	kilograms per milligram
L/day	liters per day
LHSU	lower hydrostratigraphic unit
LOAEL	lowest-observed adverse effect level
m^3/hr	cubic meters per hour
m^3-yr/kg/day	cubic meter-year per kilogram per day
MARSSIM	Multi-Agency Radiological Survey and Site Investigation Manual
MDL	method detection limit
mg/cm^2	milligrams per square centimeter
mg/day	milligrams per day
mg/kg	milligrams per kilogram
mg-yr/kg/day	milligram-year per kilogram per day
MIDEQ	Michigan Department of Environmental Quality

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ACRONYMS

mrem	millirem
mrem/pCi	millirems per picocurie
mrem/pCi/g	millirems per picocurie per gram
NAS	National Academy of Science
NCEA	National Center for Environmental Assessment
NCRP	National Council on Radiation Protection and Measurement
NOAEL	no observed adverse effect level
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
OU	Operable Unit
PARCC	precision, accuracy, representativeness, completeness, and comparability
PCB	polychlorinated biphenyl
pCi	picocurie
pCi/g	picocuries per gram
pCi/L	picocuries per liter
PCOC	potential contaminant of concern
Pe	negative logarithm of the electron activity
pH	hydrogen ion activity
PMJM	Preble's meadow jumping mouse
PPRTV	provisional peer reviewed toxicity value
PQL	practical quantitation limit
PRC	
PRG	preliminary remediation goal
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
RESRAD	Residual Radioactivity Computer Code
RFCA	Rocky Flats Cleanup Agreement
RfD	reference dose
RFETS or Site	Rocky Flats Environmental Technology Site
RFI/RI	RCRA Facility Investigation/Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RL	reporting limit

ACRONYMS

RMA	Rocky Mountain Arsenal
RME	reasonable maximum exposure
ROC	receptor of concern
RPD	relative percent difference
RSAL	radionuclide soil action level
SAP	Sampling and Analysis Plan
SCM	Site Conceptual Model
SCMTM	Sitewide Conceptual Model Technical Memorandum
SMDP	scientific management decision point
SSL	soil screening level
STSC	Superfund Technical Support Center
tESL	threshold ecological screening level
TRV	toxicity reference value
TSS	total suspended solids
UBC	Under Building Contamination
UHSU	upper hydrostratigraphic unit
UL	upper limit daily nutrient intake
USFWS	U.S. Fish and Wildlife Service
V&V	verification and validation
WQC	water quality criteria
WRV	wildlife refuge visitor
WRW	wildlife refuge worker
yr/pCi/g	years per picocurie per gram

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1.0 INTRODUCTION

This document was prepared under Task 8, Prepare the Comprehensive Risk Assessment (CRA) Work Plan, of the Final Work Plan for the Development of the Remedial Investigation/ Feasibility Study (RI/FS) (DOE 2002a) and describes the scope, activities, and methodology for the Draft CRA. The Draft CRA is referred to hereafter as the CRA. The purpose of the CRA is to assess human health and ecological risks[1] posed by chemicals, metals, and radionuclides remaining at the Rocky Flats Environmental Technology Site (RFETS or Site) following accelerated actions. The CRA will support the Draft RI/FS Detailed Analysis of Alternatives, Proposed Plan, and Corrective Action Decision/Record of Decision (CAD/ROD) for the Site.

The tasks associated with this Methodology have evolved since publication of the RI/FS Work Plan. Task 8 of the Work Plan identifies 10 items that will be included in the CRA Work Plan and Methodology:

1. Data quality objectives (DQOs);
2. Site Conceptual Model (SCM), including exposure scenarios, exposure pathways, and receptors;
3. Final list of contaminants of concern (COCs) following statistical evaluation and preliminary screening;
4. Reasonably foreseeable anticipated land use and use restrictions for the Site;
5. Background concentrations for COCs;
6. Established detection limits for COCs;
7. COC physical and chemical characteristics;
8. Methods for conducting the exposure assessment, toxicity assessment, and risk characterization;
9. Fate and transport models used to predict exposure point concentrations (EPCs); and
10. Preliminary remediation goals (PRGs) for surface soil, sediments, and groundwater from a human health and ecological perspective.

Items 1, 2, 4, 8, and 10 are addressed directly in this Methodology. Items 3, 5, and 7 will be completed using methods discussed herein and reported in the CRA. Item 6 was included in the Industrial Area (IA) and Buffer Zone (BZ) Sampling and Analysis Plans (SAPs) (DOE 2001, 2002b) and will be included in the IABZSAP (DOE 2004a) currently in Draft. Item 9 is discussed below in general and will be presented in depth in a separate groundwater modeling report. For Item 10, human health PRGs that have not been included in the Rocky Flats Cleanup Agreement (RFCA) will be referred to as "screening-level PRGs" to distinguish them from those that have been reviewed for inclusion in RFCA. These PRGs have been developed specifically

[1] In this document, the term "risk" will be used to refer to the combined "lifetime excess cancer risk" for humans and noncarcinogenic health effects assessed using the hazard index (HI) for humans, and the calculated HI for ecological receptors.

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for the CRA and will not be added to RFCA. Human health screening-level PRGs are presented in this Methodology (Appendix A). It was decided, in consultation with the regulatory agencies, that ecological PRGs would not be calculated. Instead, ecological screening levels (ESLs) have been developed and are presented in Appendix B.

1.1 Comprehensive Risk Assessment Scope

> **Scope:** The CRA will quantify and report risks posed by residual contamination at the Site to human and ecological receptors after accelerated actions.

RFCA adopted an accelerated action cleanup approach to expedite remedial work and maximize early risk reduction at the Site, as described in RFCA paragraph 79 (DOE et al. 1996). The CRA will be conducted in a progressive approach as accelerated actions are completed and data on the nature and extent of contamination are collected during the Sitewide RI/FS effort. After accelerated actions, the need for further actions, if any, will be analyzed in the Draft RI/FS, hereafter referred to as the RI/FS. Risks to human and ecological receptors posed by residual contamination at the Site will be quantified and evaluated in the CRA. The CRA will be included in the RI/FS Report.

A primary task associated with the CRA is the development of the Final CRA Work Plan and Methodology, hereafter referred to as the CRA Methodology. This CRA Methodology presents the approach and methods to be used in the CRA and documents the SCM, exposure scenarios, exposure factors, toxicity assessment, and risk characterization. The CRA Methodology is a major revision to and supersedes the previously circulated Draft Methodology (DOE 2000). This revision was required due to the change of the reasonably anticipated future use of RFETS as a wildlife refuge as designated by the Rocky Flats National Wildlife Refuge Act of 2001. This designation means that it is unlikely that RFETS would be used for limited industrial, unrestricted open space, or on-site residential uses. The CRA is based on the assumption that the future land use for the Site will be a wildlife refuge, as designated by the Act.

The CRA will assess all areas within the RFETS boundary. For Operable Unit (OU) 3, Offsite Areas, a risk assessment was performed (DOE 1996a) and a CAD/ROD was issued (DOE 1997). The OU 3 risk assessment will be reviewed and summarized in the CRA. However, OU 3 will not be reassessed unless the on-site assessment indicates circumstances that could alter the conclusions of the earlier OU 3 assessment. Information that will be evaluated in this regard includes surface water and air monitoring data collected at the Site boundary, and new soil and surface water data acquired during accelerated actions. Areas to be addressed within the RFETS boundary include areas containing existing or former OU designations. While CAD/RODs have been issued for some of these OUs (OU 1, OU 11, OU 15, and OU 16), these areas are included to simplify the analysis process and enable a CRA for each designated exposure unit (EU) within the RFETS boundary.

1.2 Technical Approach

The primary tasks required to complete the CRA, and their interrelationships, are detailed in this section. A generalized flow of the process is shown on Figure 1.1. Primary tasks include the following:

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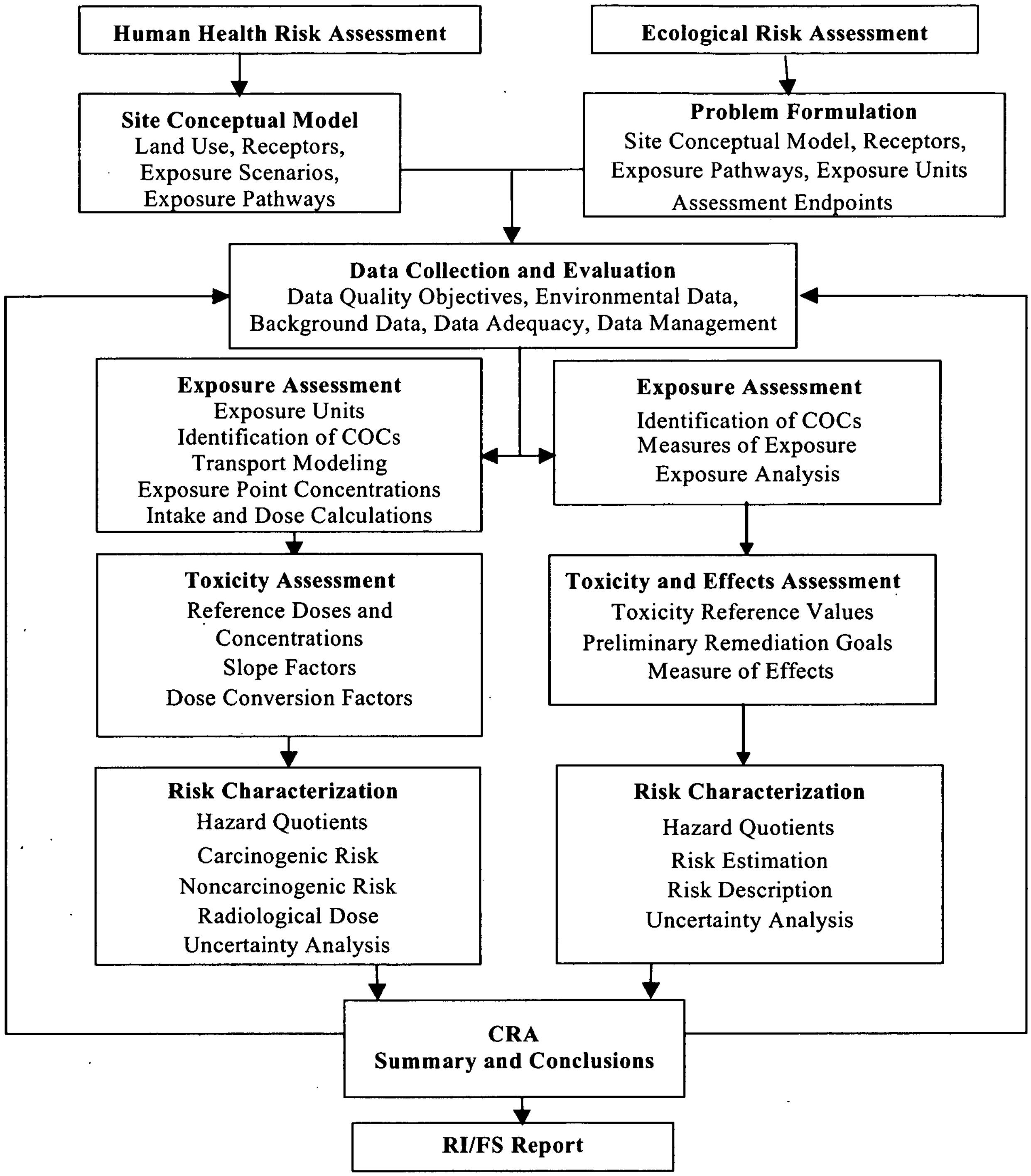
Figure 1.1 CRA Process



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- Generate the SCMs for both human health and ecological assessments with all defined exposure pathways, receptors, and scenarios;
- Identify exposure factors;
- Develop EUs;
- Update human health PRGs and develop human health screening levels for the CRA; and
- Develop ecological screening levels for the CRA.

The human health risk assessment (HHRA) and ecological risk assessment (ERA) will be conducted in parallel. The CRA will assess residual contamination using all available data including historical samples, monitoring data, and characterization and post-cleanup confirmation sampling results.

2.0 HUMAN HEALTH SITE CONCEPTUAL MODEL

Action: Develop a SCM of receptors, exposure scenarios, and exposure pathways to guide the CRA process.

The reasonably anticipated future land use for RFETS is a wildlife refuge. The U.S. Department of Energy (DOE) will be responsible for stewardship activities, such as monitoring and maintenance, within those areas associated with a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedy, as appropriate. Refuge workers are assumed to be present on site for most of the year and engaged in refuge maintenance and ecological work activities. A Comprehensive Conservation Plan is under development by the U.S. Fish and Wildlife Service (USFWS) (anticipated completion December 2004), in consultation with the Stakeholders. Specific refuge activities will be determined by this plan.

An exposure pathway describes a specific environmental route by which an individual receptor could be exposed to contaminants present at or originating from a site. After the primary source(s) and release mechanisms are identified for the site, the resulting secondary sources and secondary release mechanisms are identified and described. Subsequent sources and release mechanisms are identified until the exposure pathways for each contaminant are fully delineated. A complete exposure pathway includes five necessary elements: source, mechanism of release, transport medium, exposure point, and intake route. If any of these elements are missing, the pathway is incomplete.

Exposure pathways and exposure routes in the SCM have been categorized as significant (S), insignificant (I), or incomplete (IC) using best professional judgment in consultation with the U.S. Environmental Protection Agency (EPA), Colorado Department of Public Health and Environment (CDPHE), and USFWS. All such judgment will be supported by an analysis of the available evidence. The rationale and justification for the classification of all exposure pathways will be included in the CRA Report. Significant and insignificant exposure pathways are complete exposure pathways. Significant exposure pathways contribute the major portion of risk or dose. An insignificant pathway is complete but will not contribute significantly to the total

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risk or dose. An incomplete exposure pathway is missing one or more of the five elements necessary for a complete exposure pathway. With an incomplete pathway, there will be no exposure, and the pathway will not contribute any risk or dose. All significant exposure pathways will be quantitatively assessed at RFETS, while insignificant and incomplete exposure pathways will be qualitatively addressed.

The comprehensive human health SCM, including all potentially viable exposure scenarios and pathways, is presented on Figure 2.1. Receptors in the SCM are described in detail below. Exposure factors for each significant pathway are presented in Section 4.0.

2.1 Receptors

Two types of receptors are associated with the wildlife refuge land use: the wildlife refuge worker (WRW) and the wildlife refuge visitor (WRV). These scenarios are evaluated in the SCM and will be assessed in the CRA. It is assumed that the WRW is exposed to outdoor contaminants for an average of one-half the workday. Current planning by USFWS does not include year-round offices or an on-site visitor center. A seasonally staffed visitor contact station may be built on the western side of the Site (USFWS 2003). If an office/visitor center was built on site, there could be exposures to contaminants transported into the building for an average of one-half the workday for the WRW. This potential exposure for the WRW will be assessed in each EU. The WRV will have very limited exposures to indoor contaminants. Primary exposures will be to outdoor contaminants. Therefore, indoor exposures will not be assessed for the WRV.

Risks to an off-site resident were assessed in the OU 3 Resource Conservation and Recovery Act (RCRA) Facility Investigation/Remedial Investigation (RFI/RI) performed in 1996 (DOE 1996a). Monitoring at the Site boundaries since completion of the RFI/RI indicates that there have been no releases from the Site that would alter the conclusions of the 1996 assessment. Unless the on-site assessment indicates circumstances that could alter the conclusions of the 1996 OU 3 assessment, risks to the off-site resident will not be assessed. Current risks to an off-site receptor due to air transport are assessed in the annual National Emission Standards for Hazardous Air Pollutants Report for Radionuclides and the Annual Dose Assessment Report. The on-site resident will not be assessed because residential use is not a reasonably anticipated land use.

Ecological receptors have been identified and will be assessed in appropriate habitats as discussed in Section 7. The key ecological receptors have been selected to adequately represent the local ecological community and quantify the range of potential impacts.

2.2 Human Health Exposure Scenarios

The following exposure scenarios define the exposure pathways and assumptions for the WRW and WRV. Insignificant and incomplete exposure pathways are also defined and discussed. Justification for the classifications of exposure pathways will be included in the CRA. If preliminary calculations or information suggest that a pathway is significant, the classification will be changed.

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Figure 2.1 Human Health Site Conceptual Model

Primary Source	Primary Release Mechanism	Affected Media	Secondary Release Mechanism	Affected Media	Pathway Number	Wildlife Refuge Worker Exposure Pathways	Wildlife Refuge Visitor Exposure Pathways
Soil Subsoil Sediment Building Rubble	Stormwater Runoff (S)	Surface Water Streams / Seeps	Direct Contact		S-1	Oral (I) Dermal (I)	Oral (I) Dermal (I)
			Biotic Uptake	Fish	S-2	Oral (IC)	Oral (IC)
			Ingestion	Deer/Grazing Animals	S-3	Oral (IC)	Oral (I)
	Infiltration Percolation (I)	UHSU Groundwater	Percolation	LHSU Groundwater	I-1	Oral (IC) Dermal (IC)	Oral (IC) Dermal (IC)
			Domestic Use		I-2	Oral (IC) Dermal (IC)	Oral (IC) Dermal (IC)
			Surface water		I-3	Oral (I) Dermal (I)	Oral (I) Dermal (I)
	Volatilization (V)	Groundwater Subsurface Soil	Volatilization	Indoor Air	V-1	Inhalation (I)	Inhalation (IC)
				Outdoor Air	V-2	Inhalation (I)	Inhalation (I)
		Surface Water	Volatilization	Outdoor Air	V-3	Inhalation (I)	Inhalation (I)
	Resuspension (R)	Airborne Particulates		Indoor Air	R-1	Inhalation (S)	Inhalation (IC)
				Outdoor Air	R-2	Inhalation (S)	Inhalation (S)
			Deposition	Deer/Grazing Animals	R-3	Oral (IC)	Oral (I)
	Plant Uptake (P)	Vegetation	Ingestion	Deer/Grazing Animals	P-1	Oral (IC)	Oral (I)
	Direct Contact (D)	Surface Soil (0 to 0.5 foot)[a]			D-1	Oral (S) Dermal (S[b])	Oral (S) Dermal (S[c])
		Subsurface Soil (0.5 to 8 feet)			D-2	Oral (S) Dermal (S[b])	Oral (IC) Dermal (IC)
		Subsurface Soil (Below 8 feet)			D-3	Oral (IC) Dermal (IC)	Oral (IC) Dermal (IC)
		Sediment[a]			D-4	Oral (S) Dermal (S[b])	Oral (S[b]) Dermal (S[b])
		Building Rubble			D-5	Oral (IC) Dermal (IC)	Oral (IC) Dermal (IC)
	Radioactive Decay (E)	Surface Soil			E-1	External Irradiation (S)	External Irradiation (S)
		Subsurface Soil			E-2	External Irradiation (I)	External Irradiation (I)
		Sediment			E-3	External Irradiation (S)	External Irradiation (I)
		Building Rubble			E-4	External Irradiation (I)	External Irradiation (I)

a. Surface soil and sediments to a depth of 0.5 foot will be combined for the exposure assessment.

b. Dermal exposures will be assessed for organic COCs only.

Key to Exposure Pathways:

S - Significant
I - Insignificant
IC - Incomplete

2.2.1 Wildlife Refuge Worker Exposure Scenario

The WRW scenario for the CRA (Section 4.1.2) is consistent with the WRW scenario used for development of RFETS radionuclide soil action levels (RSALs) (EPA et al. 2002). The CRA assumes that the WRW will spend 50 percent of their work-time outdoors on the Site and the remaining 50 percent of their work day will be spent in an indoor office. Indoor exposures will only be assessed for areas outside the Institutional Control Area (ICA) (DOE et al. 2004). No buildings will be allowed in the ICA (Figure 2.2). The WRW will conduct fieldwork on Site that will result in exposure to soil, subsoil, sediment, and surface water. The WRW will be exposed to residual surface contaminants in the ICA, as well as all other on-site locations. Figure 2.2 shows the location of the ICA that will be subject to institutional controls. While DOE may retain administrative jurisdiction over some areas of the ICA, the reasonably anticipated future land use for the Site is a wildlife refuge. Therefore, the ICA will be assessed using the WRW receptor.

Monitoring, maintenance, and other long-term stewardship activities to implement and evaluate the continuing protectiveness of the comprehensive final remedy will occur on Site. The exposure parameters and pathways due to these activities are contained within the WRW scenario. It is assumed that exposures due to monitoring, maintenance, and other stewardship activities will be less than that for the WRW scenario. This is because environmental workers will conduct work in accordance with appropriate Site Health and Safety Plans (HASPs) (as Site workers do currently) and appropriate protective equipment will be used. Consequently, these individuals will not be exposed to contaminants at any higher concentrations than those to which the WRW is exposed, and the exposure frequency will be low. Therefore, the WRW scenario provides an upper bound for risks due to these activities, and a specific "stewardship receptor" will not be assessed in the CRA.

Complete Exposure Pathways for the Wildlife Refuge Worker

Potentially complete exposure pathways from which exposures are expected for the WRW include:

- Ingestion of and dermal exposures to surface soil/sediments, subsurface soil, and surface water;
- Inhalation of volatiles and particulates; and
- External exposure to beta and gamma radiation from radionuclides present in soil, subsurface soil, sediments, and building rubble.

Complete and Significant Exposure Pathways for the Wildlife Refuge Worker

The exposure pathways for the WRW that are expected to be both complete and have the possibility of contributing significant risk are:

- Inhalation of surface soil, sediments, and subsurface soil particulates;
- Ingestion of surface soil and subsurface soil/sediments;

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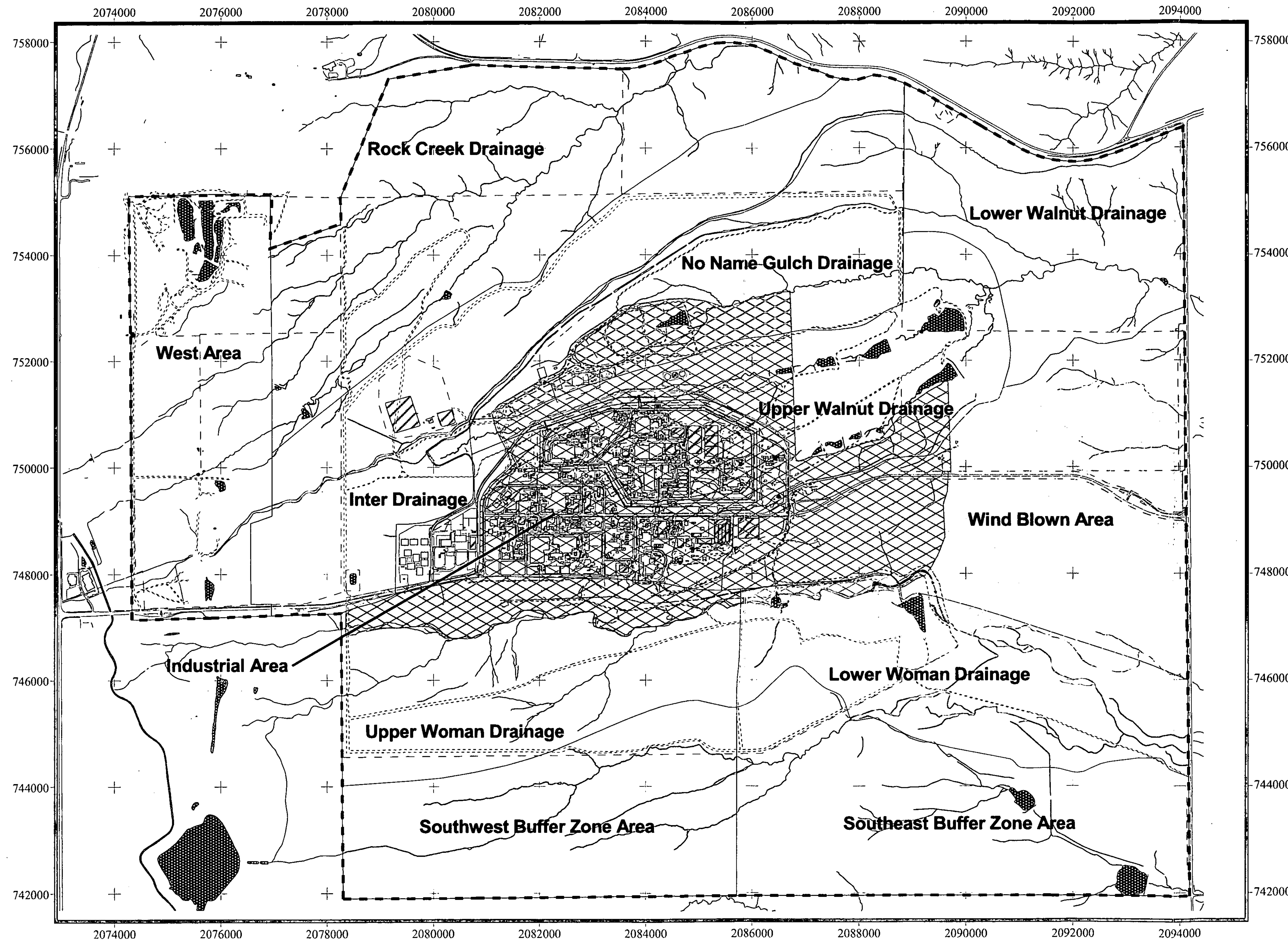
Figure 2.2 The Institutional Control Area



KEY

Institutional control area
- Landuse controls
- Restrictions on surface disturbance only
- Streams, ditches, or other drainage feature
- Paved road
- Dirt road
- Lakes and ponds
- Fence

Building
- Demolished
- Standing
- Site boundary

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N W E S

700 0 700 Feet

Scale = 1:27500

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD 27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

Prepared by: Date:04.06.04

RADMS

Prepared for:

KAISER•HILL COMPANY

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- Dermal exposure to surface soil/sediments and subsurface soil; and
- External irradiation exposure from surface soil, sediments, and subsurface soil.

Complete but Insignificant Exposure Pathways for the Wildlife Refuge Worker

Best professional judgment has been used to designate exposure pathways that are considered complete, but are not anticipated to contribute significantly to Site risks to the WRW. This is generally due to a variety of factors that lead to low intakes. The rationale and justification for the classification of all exposure pathways will be included in the CRA Report. The following pathways are considered insignificant:

- Ingestion of surface water;
- Dermal exposure to surface water;
- Inhalation of volatiles from groundwater;
- Inhalation of volatiles from surface soil and subsurface soil; and
- External irradiation exposure from subsurface soil and building rubble.

Incomplete Exposure Pathways for the Wildlife Refuge Worker

Best professional judgment has been used to designate exposure pathways that are considered incomplete. Incomplete pathways imply that exposures are not anticipated and consequently will not contribute to Site risks to the WRW. The rationale and justification for the classification of all exposure pathways will be included in the CRA Report. The following pathways are considered incomplete:

- Ingestion of fish and/or deer/grazing animals from the Site;
- Ingestion of groundwater;
- Ingestion of homegrown produce; and
- Ingestion of building rubble.

2.2.2 Wildlife Refuge Visitor Exposure Scenario

The WRV scenario is based on the open space scenario used in the RSAL Report (EPA et al. 2002). The WRV includes both a child and adult who visit the Site 100 days/year for 2.5 hours/day, for a total of 250 hours/year. The remaining time is spent off site. Outdoor recreational activities will primarily be on and near established hiking trails. Hunting may be allowed on a very limited basis, possibly by lottery. It is assumed that this receptor may be exposed to residual contaminants. It is also assumed that the WRV will not conduct activities resulting in significant exposure to subsurface soil and surface water.

Complete Exposure Pathways for the Wildlife Refuge Visitor

Potentially complete exposure pathways from which exposures are expected for the WRV include:

- Ingestion of and dermal exposures to surface soil/sediments, subsurface soil, and surface water;

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- Ingestion of deer and/or grazing animals;
- Inhalation of volatiles and particulates; and
- External exposure to beta and gamma radiation from radionuclides present in soil, subsurface soil, sediments, and building rubble.

Complete and Significant Exposure Pathways for the Wildlife Refuge Visitor

The exposure pathways for the WRV that are considered both complete and have the possibility of contributing significant risk are:

- Inhalation of surface soil/sediment particulates;
- Ingestion of surface soil/sediments;
- Dermal exposure to surface soil/sediments; and
- External irradiation exposure from surface soil/sediments.

Complete but Insignificant Exposure Pathways for the Wildlife Refuge Visitor

Best professional judgment has been used to designate exposure pathways that are considered complete, but are not anticipated to contribute significantly to Site risks to the WRV. An insignificant designation is generally due to a variety of factors that lead to low intakes. The rationale and justification for the classification of all exposure pathways will be included in the CRA Report. The following pathways are considered insignificant for the WRV:

- Ingestion of surface water;
- Dermal exposure to surface water;
- Ingestion of deer and/or grazing animals;
- Inhalation of outdoor air volatiles from surface water and groundwater;
- Inhalation of outdoor air volatiles from surface and subsurface soil;
- Inhalation of indoor air on Site; and
- External irradiation exposure from subsurface soil and building rubble.

Incomplete Exposure Pathways for the Wildlife Refuge Visitor

Best professional judgment has been used to designate exposure pathways that are considered incomplete. The rationale and justification for the classification of all exposure pathways will be included in the CRA Report. The following pathways are not anticipated to result in exposures, will not contribute to Site risks, and are considered incomplete for the WRV:

- Ingestion of groundwater; and
- Ingestion of building rubble.

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3.0 DATA COLLECTION AND EVALUATION

> **Actions:** Identify data needs and data sources, assemble data, and evaluate data quality and adequacy.

Data evaluation and aggregation will be performed on an EU basis for the HHRA and ERA. Data will also be aggregated on a Sitewide basis for some ecological receptors (Section 7). The EUs are defined in Section 4.2. The methods are described below. The DQO process specifies project decisions and techniques necessary to generate quality data and make associated conclusions (EPA 2000a). The DQO process will be used to:

- Define stated objectives;
- Define appropriate data collection methods;
- Establish necessary data types;
- Conduct data aggregation; and
- Specify acceptable levels of data quantity and quality necessary to support the risk assessment process.

Nature and extent data that have been collected historically at RFETS, and also progressively during RI/FS investigations and accelerated actions, will be identified and assembled. All environmental data for the Site are collected under agency-approved SAPs and standardized contract required analytical procedures. Verification and data quality assessment (DQA) procedures will be used to verify the quality and comparability of collected data. Accelerated actions are currently being conducted for specific areas of contamination based on comparison of data to human health action levels (ALs). Confirmation samples are being collected following these actions. Data that are no longer relevant due to accelerated actions will be replaced with the confirmation sampling data in order to reflect the current concentrations following accelerated actions. COCs will be identified to support the comprehensive HHRA and ERA. Risks will be quantified, evaluated, and summarized for receptors by exposure scenarios and pathways for established EUs (as defined in Sections 4.2 and 7), and Sitewide (as defined in Section 7).

Site data will be used to evaluate residual contamination and determine contaminant distributions. Exposure parameters, such as inhalation and ingestion rate, exposure frequency, and exposure duration, have been determined for identified Site-specific receptors. Toxicity data will be collected to identify or derive dose limits to human and ecological receptors. Physical and chemical parameters for all viable COCs will also be collected, as necessary, to support a complete toxicity assessment, assessment of impacts to receptors, and determination of environmental fate and transport mechanisms. Radiological data for pertinent radionuclides, including plutonium-239, americium-241, uranium-235, and uranium-238, will be collected to determine recent dose conversion factors (DCFs) and radiological emission data. Ecological data, such as historical ecological, biological, and

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habitat information that have been collected for the Site will be compiled and used to support assumptions for habitat usage, ecological exposures, and risk characterization for the ERA. The underlying principles for establishing the DQOs for the human health and ecological assessments are generally similar; however, Site use by humans versus ecological receptors and data needs differ. Therefore, the human health and ecological DQO processes have been presented separately. DQOs specific to the ERA process are provided in Section 7.

3.1 Comprehensive Risk Assessment Data Quality Objectives

The CRA follows the EPA DQO process to ensure that the type, quantity, and quality of environmental data used in decision making are appropriate for the intended purpose (EPA 2000a). The DQO process consists of seven steps that specify project decisions, the data quality required to support those decisions, specific data types needed, data collection requirements, and analytical techniques necessary to generate the specified data quality. During the first six steps of the DQO process, the planning team develops decision performance criteria (that is, DQOs) for the data collection design. All decision rules need to be considered, as appropriate. The final step of the process involves developing the data collection design based on the DQOs.

3.1.1 Step 1: State the Problem

Risks from exposure to residual contaminants present in environmental media at RFETS must be quantified to determine whether endstate long-term land use is protective and within the range of acceptable risk. The nature and extent of COCs must be adequately determined to quantify human health and ecological risks at RFETS. Sufficient data must be available to the risk assessor to define the EPC, which is an estimate of the long-term concentration to which a receptor is exposed. The EPC incorporates the spatial and temporal variability of contaminant concentrations, and reflects the random and long-term access of the receptor to the exposure area.

The problem is:

> *"The long-term average exposure of human and ecological receptors to contaminants in all media in an EU must be estimated for the CRA."*

3.1.2 Step 2: Identify the Decision

The primary decision is:

> *"Are risks to receptors at RFETS following exposure to residual contamination acceptable based on the reasonably anticipated future land use?"*

Resolution and documentation of the following key secondary decisions will be required to ensure completion of the CRA. Each of these is discussed in the following sections of this document.

- Has a methodology been developed to adequately assess human health risks?
- Has a methodology been developed to adequately identify COCs?

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- Is the CRA SCM adequate to define all viable exposure scenarios, exposure pathways, and receptors based on the reasonably anticipated future land use?
- Have all EUs been adequately defined and established?
- Have the nature and extent of inorganic, organic, and radionuclide analytes within EUs been identified with adequate confidence, based on evaluation of Site process knowledge and analytical data?
- Have sufficient samples been collected to adequately estimate the long-term average exposure of receptors to contaminants in all media in an EU?

3.1.3 Step 3: Identify the Inputs to the Decision

Available Site historical information, sampling data, and the CRA Methodology and requirements will be used to determine adequate sampling locations and densities for EUs.

The CRA DQA methodology (Section 3.1.5) will be applied to all data used in the CRA. The DQA procedures generally follow the EPA guidelines in EPA's Guidance for Data Usability in Risk Assessment, Parts A and B (EPA 1992a, 1992b).Data will be screened through the COC selection process as described in Section 4.4. All data will also be screened using professional judgment to ensure they meet risk assessment needs. The rationale and justification will be documented in the CRA Report. All selected COCs will be used to calculate risks to receptors.

3.1.4 Step 4: Define the Study Boundaries

Study boundaries are used to define the spatial and temporal boundaries for data collection in support of the decision to quantify risk to receptors. Environmental media analyte data will be assessed for surface soil and sediments to a depth of 6 inches, and for subsurface soil from 6 inches to 8 feet. Existing environmental media data will be used when possible and additional sampling will be conducted if determined to be necessary. Sufficient samples will be collected to statistically evaluate the data, identify COCs, and quantify risk to receptors. These results will be used in the CRA.

The assessment will be confined to the area within the RFETS boundary unless the onsite assessment indicates circumstances that could alter the conclusions of the assessment performed earlier for OU 3, Off-Site Areas (DOE 1996a).

Functional EUs for the WRW and WRV receptors have been established based on watersheds, known patterns of contamination, and expected activity patterns. Known Individual Hazardous Substance Sites (IHSSs), Potential Areas of Concern (PACs), and Under Building Contamination (UBC) Sites of special interest will be included in the EU assessments. Analyte data will be aggregated at the EU level to quantify risk to human receptors.

Statistical evaluation of environmental data will include standard descriptive calculations; precision, accuracy, representativness, completeness, and comparability (PARCC) parameter analyses; distribution testing; population testing of Site data relative to background; nonparametric tests; and probabilistic resampling techniques, such as Bootstrapping and power calculations.

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3.1.5 Step 5: Identify the Data Adequacy Decision Rules

This section presents the decision rules to determine data adequacy for both the human health and ecological risk assessment portions of the CRA. The nature and extent of organics, inorganics, and radionuclides must be determined with sufficient certainty to permit adequate quantification of statistical analyses EPCs, and quantification of risk to receptors. Sufficient samples must be collected to adequately estimate the long-term average exposure of receptors to contaminants in all media in an EU. Adequate characterization will ensure that EPCs are representative of the areas to be assessed. The placement of samples Sitewide will be assessed to ensure that sources of contamination are well characterized and that the adequacy of the EPC can be determined. Data adequacy criteria must, therefore, be met or additional sampling and analysis will have to be performed.

Data Adequacy Assessment

The following decision rules will be used to determine whether analyte data are adequate to support statistical, exposure, and risk calculations:

- If one or more metal and radionuclide surface soil sample is available per 30-acre block outside of source areas, data will be considered sufficient. If not, one composite sample will be collected in each 30-acre area, as described in the CRA Sampling Addendum 04-01 Phase 1 (DOE 2004b).
- If there is one radionuclide sediment sample per approximately 1,000 feet of stream bed along the major drainages, data will be considered sufficient. If not, targeted samples will be collected as necessary.
- If a detected organic, inorganic, or radionuclide analyte in a source area is above background and above 0.5 times the human health PRG or the ecological screening level (ESL) in a source area, continue with the data adequacy assessment. If not, drop the analyte from the assessment.
- If the spatial extent in a source area of an analyte that exceeds 0.5 times the human health PRG or ESL is bounded by nondetects for organics or by background for inorganics and radionuclides, document this in the Data Adequacy Report (DAR). If not, continue with the assessment.
- If the spatial extent of organic and inorganic analytes in potential depositional areas down gradient of source areas is known, document this in DAR. If not, determine whether targeted sampling is needed.
- If analytes of interest are missing for specific locations, determine location and number of targeted samples.
- If samples are adequate, document results.
- Final sampling locations will be determined through the consultative process with the agencies.

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PARCC Parameter Assessment

Data quality and adequacy will also be assessed using a standard PARCC parameter analysis (EPA 2000b) for all data in each environmental media as described below.

Precision

For nonradiological contaminants, if the relative percent difference (RPD) between the target and duplicate, at concentrations five times the reporting limit (RL), is less than 35 percent for solids and 20 percent for liquids, the overall precision of the contaminant concentration is adequate. Otherwise, the magnitude of the imprecision must be addressed in the CRA and/or additional samples may be required (EPA 2000b).

For radiological contaminants, if the duplicate error ratio (DER) is less than 1.96, the overall precision of the contaminant concentration is adequate. Otherwise, the magnitude of the imprecision must be addressed in the CRA and/or additional samples may be required (EPA 2000b).

Accuracy

If overall accuracy for the SW-846 (EPA 1994) and alpha-spectroscopy methods comply with the National Basic Ordering Agreement (BOA), as verified through formal verification and validation (V&V) (EPA 2000b) of the results, then the results may be used in the CRA without qualification. Otherwise, the magnitude of the inaccuracy(s) must be addressed in the CRA and/or additional samples may be required.

Representativeness

Prerequisites to the decision criteria include an adequate number of valid sample results as stipulated in the Completeness section, and sample acquisition and analysis under an approved Quality Program as follows:

- If sampling locations are spatially distributed such that contaminant randomness and bias considerations are addressed, based on the site-specific history, then sample results are representative. Otherwise, the results must be qualified and/or additional samples collected.
- If samples were analyzed by the SW-846 or alpha- spectroscopy methods and results were documented accordingly, as quality records according to approved procedures and guidelines, the sample results are representative of contaminant concentrations. Otherwise, results of the CRA must be qualified and/or additional samples collected.

Completeness

Completeness will be evaluated using the following determination:

- If at least one sample for metals and radionuclides exists in each 30-acre block across the Site, the sampling is adequate.

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- If samples were collected to spatially define the distribution of an analyte in an EU, the number of samples is adequate. Otherwise, additional samples may be collected.

Comparability

Sample collection and analysis methods will be reviewed for comparability. Similarities and differences between the sample collection and analysis methods will be documented. Decisions on comparability will be made in consultation with the regulatory agencies. If chemical and radiological results are comparable within the aggregated (CRA) data set based on defined matrices and standardized units of measure (for example, picocuries per gram [pCi/g] and milligrams per kilogram [mg/kg]), the data are adequate for use in the CRA. Otherwise, the results must be converted or normalized, the CRA qualified, and/or additional samples collected (EPA 2000b).

3.1.6 Step 6: Specify Tolerable Limits on Decision Errors

Sources of uncertainties in the risk assessments will be identified, minimized, and documented in the CRA. This may include use of upper-bound numbers or ranges of values, as applicable, for various parameters considered, concentration term estimates, contaminant transport, data distribution assumptions, and EU use assumptions.

Where alpha and beta errors are applicable in statistical hypothesis testing, these errors will also be documented. Alpha error will not exceed 10 percent in sample power calculations, whereas beta error will not exceed 20 percent in sample power calculations.

3.1.7 Step 7: Optimize the Design

Based on the iterative nature of the DQO process, any decision that is not consistent with project goals will result in a reinitiation of the DQO process. If determination of the nature and extent of analytes is found to be inadequate, further sampling will be initiated. If sampling power is determined to be inadequate for any given scenario and set of analyte data, more samples will be collected and the sampling power will be recalculated.

4.0 HUMAN HEALTH EXPOSURE ASSESSMENT FOR THE CRA

Actions: Identify potential land use and exposed populations; develop the SCM, exposure factors for each pathway, and EUs for data aggregation; identify COCs; determine whether transport modeling is necessary; estimate COC EPCs; and quantify intake to receptors.

The CRA human health exposure assessment will quantitatively and qualitatively evaluate contact between human receptors and COCs. The exposure assessment will estimate the total dose or intake for a receptor in an EU for a particular land use and exposure scenario. The calculated dose is then combined with chemical-specific dose-response data to estimate risk

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(EPA 1992c). The exposure assessment methods for the HHRA are described in detail in the following sections.

4.1 Exposure Factors

This section presents the exposure factors for the HHRA.

4.1.1 Exposure Pathway Assessment

Exposure pathways, the course a contaminant takes from the source to a receptor, are shown in the SCM (Figure 2.1). In the model, exposure pathways are designated as incomplete (IC), complete and significant (S), or complete and insignificant (I) as defined previously.

Direct contact with surface soil, subsurface soil (to 8 feet in depth), and sediments; the inhalation of airborne contaminants; and exposure to penetrating radiation are the primary exposure pathways of concern. Contact with subsurface soil is considered for the WRW, but is limited both spatially and temporally (Section 4.5). Ingestion of and dermal contact with surface water and volatilization of contaminants are considered insignificant pathways. Ingestion of or dermal contact with groundwater are considered incomplete and will not be assessed. Ingestion of or dermal contact with groundwater that daylights at seeps or streams are considered to be insignificant pathways. Ingestion of animal tissue is incomplete for the WRW, but is considered insignificant for the WRV due to possible limited hunting activity. All other exposure pathways are considered incomplete and will not be addressed, including ingestion of groundwater and/or fish.

Inhalation Pathway

The inhalation pathway will be assessed for resuspension of airborne contaminants present in surface soil transported to human and ecological receptors. The receptors will be assessed for this exposure pathway using the contaminant concentration in the soil and the mass loading variable developed for the RSALs (EPA et al. 2002). Increased resuspension and exposures due to fires are accounted for the WRW and WRV in the mass loading factor as calculated by the RSALs Workgroup. The potential volatilization of contaminants from soil and shallow groundwater to receptor locations is considered an insignificant pathway. Volatilization into office space will be evaluated for WRW offices Sitewide, if determined to be a significant pathway.

Ingestion Pathway

The ingestion pathway will be assessed for direct ingestion of contaminants present in surface soil and sediments for the WRW and WRV receptors. Direct ingestion of surface water will not be assessed for the WRW and WRV receptors. Exposure to contaminants in groundwater in the upper hydrostratigraphic unit (UHSU) transported to surface water is currently considered insignificant. A preliminary assessment will be performed and reported in the CRA to justify this decision. Ingestion of deep aquifer groundwater will not be assessed as a viable exposure pathway.

Runoff from contaminated soil to nearby surface water could result in direct ingestion of contaminated surface water by all receptors and contribute to possible contamination of aquatic species. However, direct ingestion of surface water and contaminated fish collected from the area are considered insignificant and incomplete pathways, respectively, and will not be assessed. Collection of meat from hunting activities and subsequent ingestion is also considered insignificant and will not be assessed.

Dermal Exposure Pathway

Dermal exposure due to contact with contaminated soil and sediments will be assessed for the WRW and WRV receptors. Dermal exposure to surface water will not be assessed for either receptor.

External Irradiation Exposure Pathway

External irradiation exposure will be assessed for both receptors to determine impacts to human receptors resulting from exposure to external penetrating radiation emanating from radionuclides present in contaminated environmental media and associated contamination.

4.1.2 Wildlife Refuge Worker Scenario Exposure Factors

The exposure factors for the WRW are presented in Table 4.1. Factors were taken from the RSALs Task 3 Report (EPA et al. 2002) where available. Dermal exposures were not included in the RSALs. The sediment and subsurface pathways also were not assessed in the RSALs Report.

Table 4.1 CRA Exposure Factors for the On-Site WRW Receptor

Exposure Factor	Abbreviation	Units	Value	Source
Chemical concentration in medium	Cs	mg/kg/ or pCi/g	chemical-specific	
Adult body weight	BWa	kg	70	EPA 1991
Surface soil/sediment exposure frequency	EFwss	day/yr	230	EPA et al. 2002
Surface-subsurface soil/sediment exposure frequency	EFwsub	day/yr	20	DOE 2003a
Exposure duration	EDw	yr	18.7	EPA et al. 2002
Exposure time	ETw	hr/day	8	EPA et al. 2002
Exposure time fraction, outdoor	Eto_w	--	0.5	EPA et al. 2002
Exposure time fraction, indoor	Eti_w	--	0.5	EPA et al. 2002
Averaging time - noncarcinogenic	ATnc	day	6826	Calculated
Averaging time - carcinogenic	ATc	day	25550	Calculated
Soil/sediment ingestion rate	IRwss	mg/day	100	EPA et al. 2002
Skin-soil adherence factor	AFw	mg/cm^2-event	0.12[a]	EPA 2001a
Event frequency	EVw	events/day	1	EPA 2001a
Skin surface area (exposed)	SAw	cm^2	3300[b]	EPA 2001a
Soil dermal absorption fraction	ABS	--	chemical-specific	EPA 2001a
Inhalation rate	IRaw	m^3/hr	1.3	EPA et al. 2002
Dilution factor, indoor inhalation	DFi	--	0.7	EPA et al. 2002
Mass loading, (PM10) for inhalation	MLF	kg/m^3	6.7E-08[c]	EPA et al. 2002
Area correction factor	ACF	--	0.9	EPA et al. 2002
Gamma shielding factor (1-Se) outdoor	GSFo	--	1	EPA et al. 2002
Gamma shielding factor (1-Se)	GSFi	--	0.4	EPA et al. 2002

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Exposure Factor	Abbreviation	Units	Value	Source
Gamma exposure factor (annual) surface soil = (EFwss / 365 day/yr)	Te_A	--	0.7	Calculated
Gamma exposure factor (annual) subsurface soil = (EFwsub / 365 day/yr)	Te_As	--	0.05	Calculated
Gamma exposure factor (daily) outdoor = (Etw*Eto_w hr/day / 24 hr/day)	Te_Do	--	0.15	Calculated
Gamma exposure factor (daily) indoor = (8 hr/day / 24 hr/day)	Te_Di	--	0.15	Calculated
Conversion factor 1	CF1	kg/mg	0.000001	
Conversion factor 2	CF2	g/kg	1000	
Conversion factor 3	CF3	g/mg	0.001	

a. The skin soil adherence factor is the geometric mean for farmers. This value is recommended by CDPHE for use in the WRW PRGs.

b. The skin surface area value is the EPA default for commercial/industrial exposures and is the average of the 50th percentile for men and women >18 years old wearing a short-sleeved shirt, long pants, and shoes. The value was recommended by CDPHE for use in the WRW PRGs.

c. The mass loading value is the 95th percentile of the estimated mass loading distribution estimated in the RSALs Task 3 Report (EPA et al. 2002).

4.1.3 Wildlife Refuge Visitor Scenario Exposure Factors

Current plans for the wildlife refuge include public uses similar to open space usage previously developed for RFETS, with trails for wildlife observation, hiking, and biking (USFWS 2003). The exposure time and duration factors for the WRV receptor, presented in Table 4.2, are based on a survey conducted by Jefferson County of open space users (Jefferson County 1996). The values were first used in the open space PRG calculations for the Site and were adapted for the RSALs Report.

Table 4.2 CRA Exposure Factors for the WRV Receptor

Exposure Factor	Abbreviation	Units	Value	Source
Concentration in medium	Cs	mg/kg or pCi/g	chemical-specific	
Adult body weight	BWa	kg	70	EPA 1991
Child body weight	BWc	kg	15	EPA 1991
Exposure frequency	EFv	day/yr	100	EPA et al. 2002[a]
Exposure duration-adult	EDav	yr	24	EPA 1991
Exposure duration-child	EDcv	yr	6	EPA 1991
Exposure duration-total	EDt	yr	30	EPA 1991
Exposure time	ETv	hr/day	2.5	EPA et al. 2002[b]
Adult averaging time - noncarcinogenic	ATancv	day	8760	Calculated
Child averaging time - noncarcinogenic	ATcncv	day	2190	Calculated
Averaging time - carcinogenic	ATc	day	25550	EPA 1991
Adult soil ingestion rate	SIRav	mg/day	50	EPA et al. 2002
Child soil ingestion rate	SIRcv	mg/day	100	EPA et al. 2002
Age-adjusted soil ingestion rate for non-radionuclides	SIRageav	mg-yr/kg-day	57	Calculated
Age-adjusted soil ingestion rate for radionuclides	SIRagav_r	mg/day	60	Calculated
Adult skin-soil adherence factor	AFav	mg/cm^2-event	0.07[c]	EPA 2001a

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Exposure Factor	Abbreviation	Units	Value	Source
Child skin-soil adherence factor	AFcv	mg/cm^2-event	0.2[d]	EPA 2001a
Event frequency	EVv	events/day	1	EPA 2001a
Adult skin-surface area (exposed)	SAav	cm^2	5700[e]	EPA 2001a
Child skin-surface area (exposed)	SAcv	cm^2	2800[f]	EPA 2001a
Age-averaged surface area/adherence factor	SFSagav	mg-yr/kg-event	361	EPA 2001a
Dermal absorption fraction	ABS	--	chemical-specific	EPA 2001a
Outdoor inhalation rate - adult	IRov	m^3/hr	2.4	EPA et al. 2002
Outdoor inhalation rate - child	IRcov	m^3/hr	1.6	EPA et al. 2002
Age-averaged inhalation factor (non-radionuclides)	IRagav	m^3yr/kgday	3.7	EPA et al. 2002
Age-averaged inhalation rate (radionuclides)	Iragav_r	m^3/hr	2.2	EPA et al. 2002
Mass loading, (PM10) for inhalation	MLF	kg/m^3	6.7 E-8[g]	EPA et al. 2002
Area correction factor	ACF	--	0.9	EPA et al. 2002
Gamma shielding factor (1-Se) outdoor	GSFo	--	1	EPA et al. 2002
Gamma exposure factor (annual) = (EFv / 365 day/yr)	Te_Av	--	0.3	Calculated
Gamma exposure factor (daily) = (ETv hr/day / 24 hr/day)	Te_Dv	--	0.1	Calculated
Conversion factor 1	CF1	kg/mg	0.000001	
Conversion factor 2	CF2	g/kg	1000	
Conversion factor 3	CF3	g/mg	0.001	

a. Value is the 95th percentile of visitation frequency for open space users (Jefferson County 1996).
b. Value is the 50th percentile of time spent for open space users (Jefferson County 1996).
c. The adult skin-soil adherence factor is the EPA residential default and the 50th percentile for gardeners. This is the value recommended by CDPHE for use in the WRW PRGs.
d. The child skin-soil adherence factor is the EPA residential default and the 95th percentile for children playing in wet soil. This is the value recommended by CDPHE for use in the open space user PRGs.
e. The adult skin-surface area value is the EPA default for residential exposures and the average of the 50th percentile for males and females >18 years old wearing short-sleeved shirts, shorts, and shoes. The value was recommended by CDPHE for use in the WRW PRGs.
f. The child skin-surface area value is the EPA default for residential exposures and the average of the 50th percentile for males and females from <1 to <6 years old wearing short-sleeved shirts, shorts, and no shoes. The value was recommended by CDPHE for use in the WRW PRGs.
g. The mass loading value is the 95th percentile of the estimated mass loading distribution estimated in the RSALs Task 3 Report (EPA et al. 2002).

4.2 Functional Exposure Units

Risk assessments evaluate the long-term threats to human health and the environment. An EU is the area over which long-term risks to the chosen receptors are assessed. The EU is an embodiment of the exposure scenario and its size varies with the land use and receptor activities. Recreational or open space EUs are generally large, depend on the recreational activities envisioned for the site, and represent the area over which a receptor ranges during recreational activities. The activities of a WRW are even more extensive and varied, and the area over which the worker will be exposed during a career is quite large.

4.2.1 Exposure Unit Development

Human health risks and health hazards will be assessed in three ways at RFETS:

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- An on-site WRW will be assessed based on exposure to COCs selected for each EU.
- An on-site WRV will be assessed based on exposure to COCs selected for each EU. The same EUs will be used for the WRV as for the WRW assessment.

The EUs for the WRW and WRV are illustrated on Figure 4.1. As stated above, sources of contamination will be determined using Site data to assess the spatial and temporal distribution of all classes of contaminants. This information will be used to support the selection of COCs. Primary areas of contamination will be identified and depicted on Site maps. Data sufficiency will be assessed.

The RFETS EUs integrate the above factors and also:

- Consider Site contaminant release patterns and distinct areas of contamination;
- Aggregate data on a watershed basis;
- Support future land use planning;
- Facilitate assessment of risk in functional areas; and
- Comply with RFCA/CERCLA requirements.

The RFETS EUs represent long-term activity areas in which the WRW and WRV will be exposed to residual contamination. The importance and relationship of the above items to long-term risks are discussed below.

Contaminant Release Patterns

Contaminant release patterns and known sources were incorporated in the delineation of the RFETS EUs, as shown on Figures 4.2 and 4.3. The objective is to assess areas with similar types of contamination on a collective basis. For example:

- The IA EU has the most IHSSs, PACs, and UBC Sites and was the area most affected by industrial activities at the Site.
- The Wind Blown Area EU includes surface soil affected by the 903 Pad release that is characterized by elevated plutonium and americium activities.
- The Upper Walnut Drainage EU includes the A- and B-Series ponds, which have elevated levels of radionuclides in sediments.
- The No Name Gulch Drainage EU encompasses the Present Landfill and downgradient areas.
- The Lower Walnut Drainage EU stream sediments are affected by surface water flows from the ponds and erosion from the Wind Blown Area.
- The Woman Drainage EU is affected by the 903 Pad, the Original Landfill, and other IHSSs and PACs.
- The remaining four EUs are not significantly affected by releases from the Site.

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Watersheds

The EUs were designed on a watershed basis. This was done to account for similar long-term fate and transport processes for residual contaminants in soil and sediments. The major surface transport process for persistent contaminants in surface soil is overland flow and transport of eroded soil in surface water. The EUs represent distinct areas affected by the potential transport of residual contamination from well-defined sources and activity areas for the WRW and WRV receptors based on similar landscapes and habitats.

Future Land Use Planning

The EUs were designed to support future land use planning by assessing risks for areas aggregated by similar geography, ecology, and expected usage. This will enable planners and managers to use the results of the CRA to determine areas of the Site to target for more intensive recreational development or other uses, such as ranger offices or a visitor center for the refuge.

Assessment of Functional Areas

The EUs are representative of expected activity areas for the WRW or WRV receptors. The areas of the EUs vary from 390 to 735 acres, as shown in Table 4.3. Time-weighted activity areas for refuge personnel calculated from survey data collected for the Rocky Mountain Arsenal (RMA) are in the same size range, according to Table 4.4. The areas were calculated using the estimated time spent in each area size class, using the following formula:

$$\textit{Time-Weighted Area} = \sum_{i=1 \text{ to } 3} (t_i/t_t * A_i) \qquad \text{(Equation 4-1)}$$

Where:

t_i = the time spent in the ith area size class by all workers

t_t = the total time spent in all area size classes by all workers

A_i = the ith area (midpoint or maximum of size range)

The EUs are also indicative of different functional areas. Activities performed in the drainages will vary from those performed in the upland areas due to variation in topography, vegetation, and habitat. The assessment of risks in the EUs will result in a complete assessment of the risks from residual contamination at the Site.

Compliance With RFCA/CERCLA Requirements

Under CERCLA, it must be shown that risks for expected land uses at the Site fall within the acceptable range of 1×10^{-6} to 1×10^{-4} cancer risks and below a hazard index (HI) of 1 for noncarcinogenic effects. The assessments for the EUs will present a comprehensive evaluation of long-term risks to the designated receptors across the Site. These results will provide estimates of residual risks from the Site following accelerated actions.

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Table 4.3 RFETS EU Areas

EU	Area (acres)
Industrial Area	428
Upper Woman Drainage	524
Lower Woman Drainage	448
Southwest Buffer Zone Area	476
Southeast Buffer Zone Area	579
Wind Blown Area	715
Upper Walnut Drainage	403
Lower Walnut Drainage	390
No Name Gulch Drainage	425
Inter-Drainage	596
Rock Creek Drainage	735
West Area	468

Table 4.4 Time-Weighted Average Activity Areas for WRWs[a]

Receptors	Parameter	Small Areas (0-10 acres)	Medium Areas (10-500 acres)	Large Areas (500-6,000 acres)
All workers	Midpoint time-weighted area (acres)	2	126	332
	Midpoint EU size (time-weighted) (acres)	460		
	Max time-weighted area (acres)	4	248	613
	Max EU size (time-weighted) (acres)	865		
Workers spending at least 50 percent of time outdoors	Midpoint time-weighted area (acres)	1.9	132	319
	Midpoint EU size (time-weighted) (acres)	453		
	Max time-weighted area (acres)	3.8	260	589
	Max EU size (time-weighted) (acres)	852		
Workers spending at least 30 percent of time outdoors and on Site 100 percent of time	Midpoint time-weighted area (acres)	2	133	425
	Midpoint EU size (time-weighted) (acres)	560		
	Max time-weighted area (acres)	3	261	784
	Max EU size (time-weighted) (acres)	1,048		
All workers spending at least 30 percent of time outdoors	Midpoint time-weighted area (acres)	1.8	132	421
	Midpoint EU size (time-weighted) (acres)	555		
	Max time-weighted area (acres)	3.5	260	777
	Max EU size (time-weighted) (acres)	1,040		

a Calculated from original survey data from Table B.2-14 (RMA IEA/RC Appendix B, 8/93) (reported times at middle and higher activities, outdoors) and from Table B.2 att 2-1, 2, 3, 4, 5, & 6 (RMA IEA/RC Appendix B, 2/15/94) (reported times doing specific tasks). Survey was performed by Shell for the Army's Baseline Risk Assessment for the RMA. WRWs from Malheur, OR (M), Minnesota Valley, MN (MV), and Crab Orchard, IL (CO) were included in the survey. Carl Spreng and Diane Niedzwiecki of CDPHE then exercised professional judgment to decide land area for each task.

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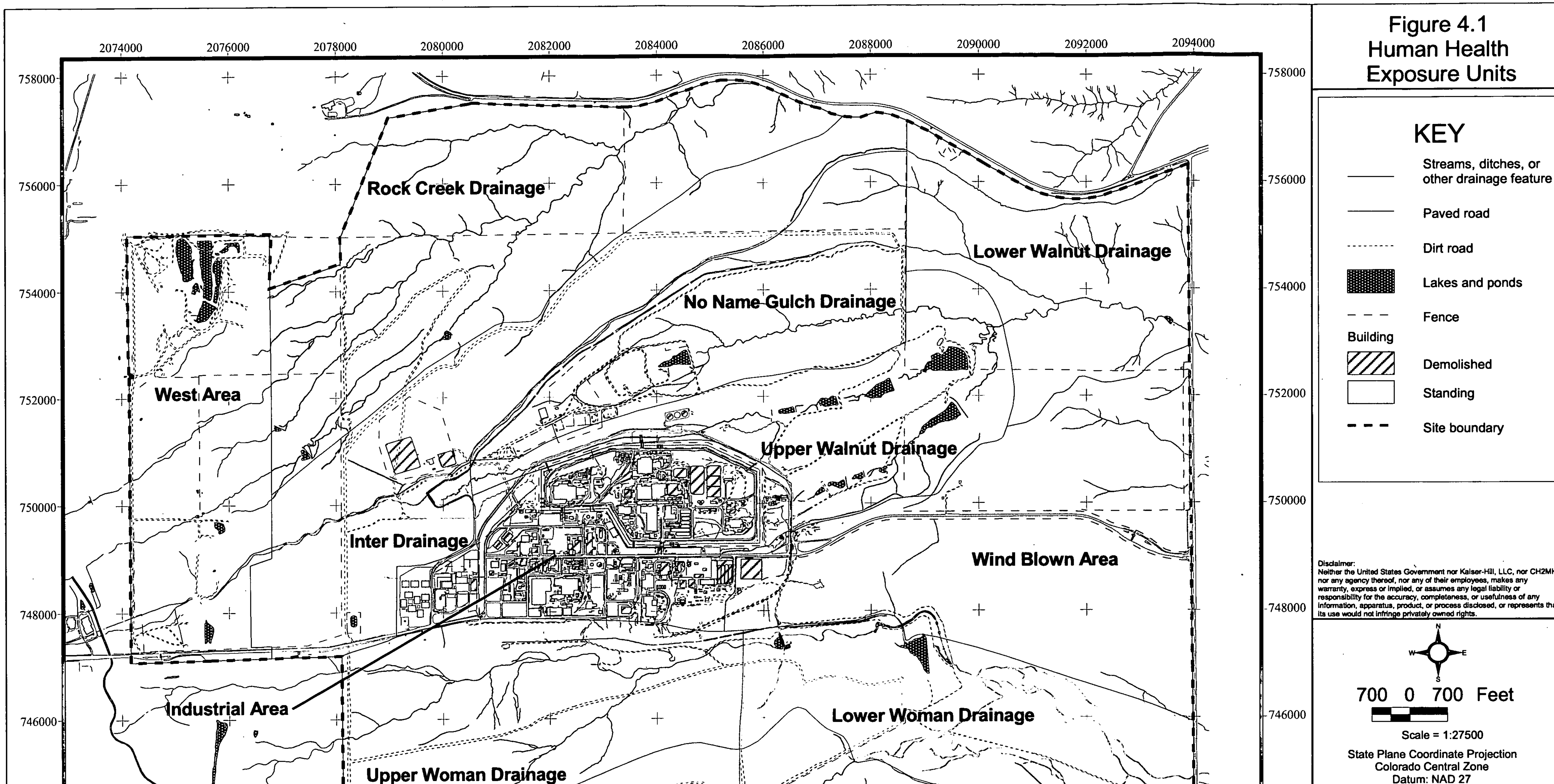
Figure 4.1
Human Health Exposure Units



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U.S. Department of Energy
Rocky Flats Environmental Technology Site

Prepared by: Date:04.06.04

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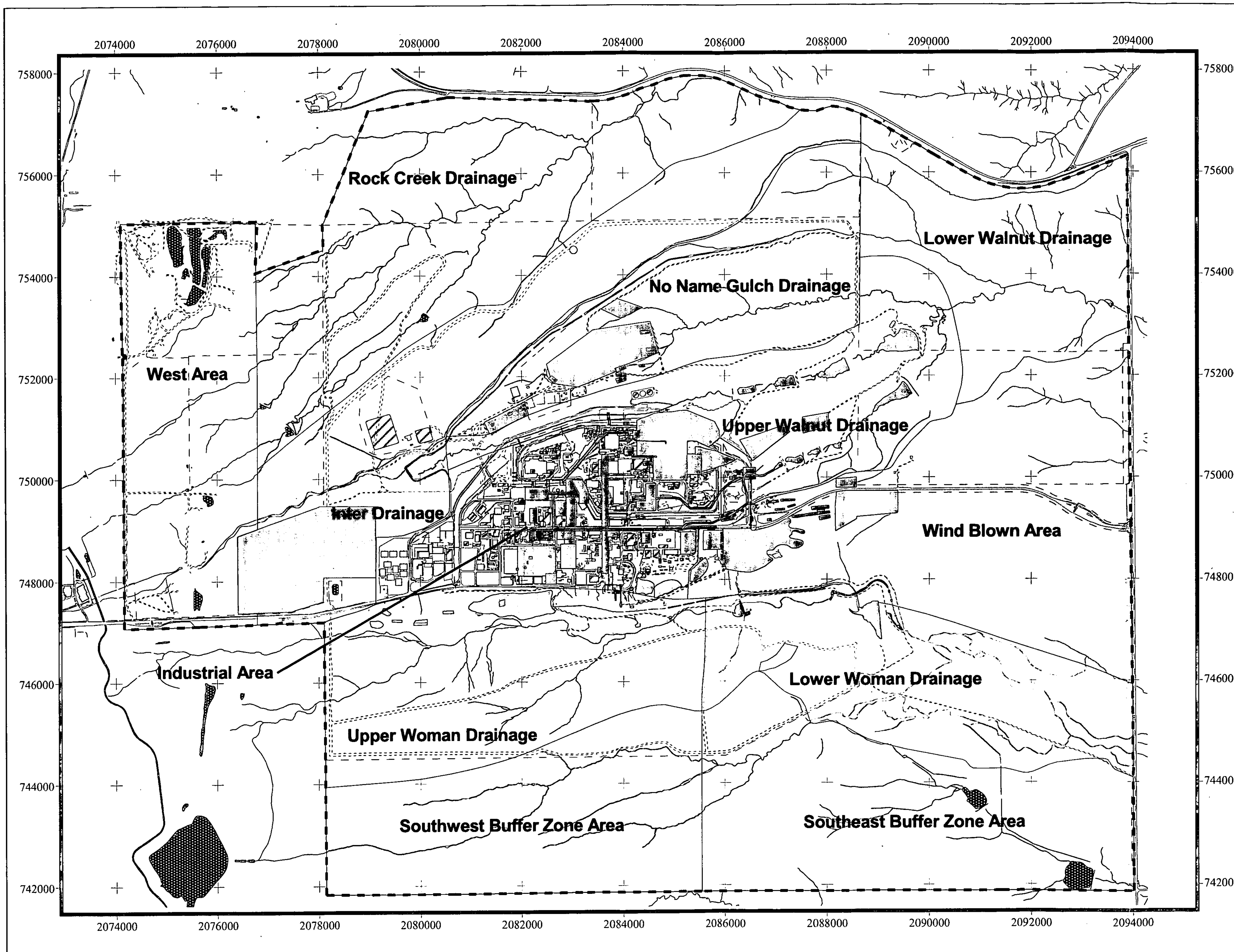

Figure 4.2
Exposure Units with IHSSs

KEY

- IHSS
- Streams, ditches, or other drainage feature
- Paved road
- Dirt road
- Lakes or ponds
- Fence

Building

- Demolished
- Standing
- Site boundary

N W E S

700 0 700 Feet

Scale = 1:27500

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD 27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

Prepared by: Date:04.06.04

RADMS

Prepared for:

KAISER•HILL
COMPANY

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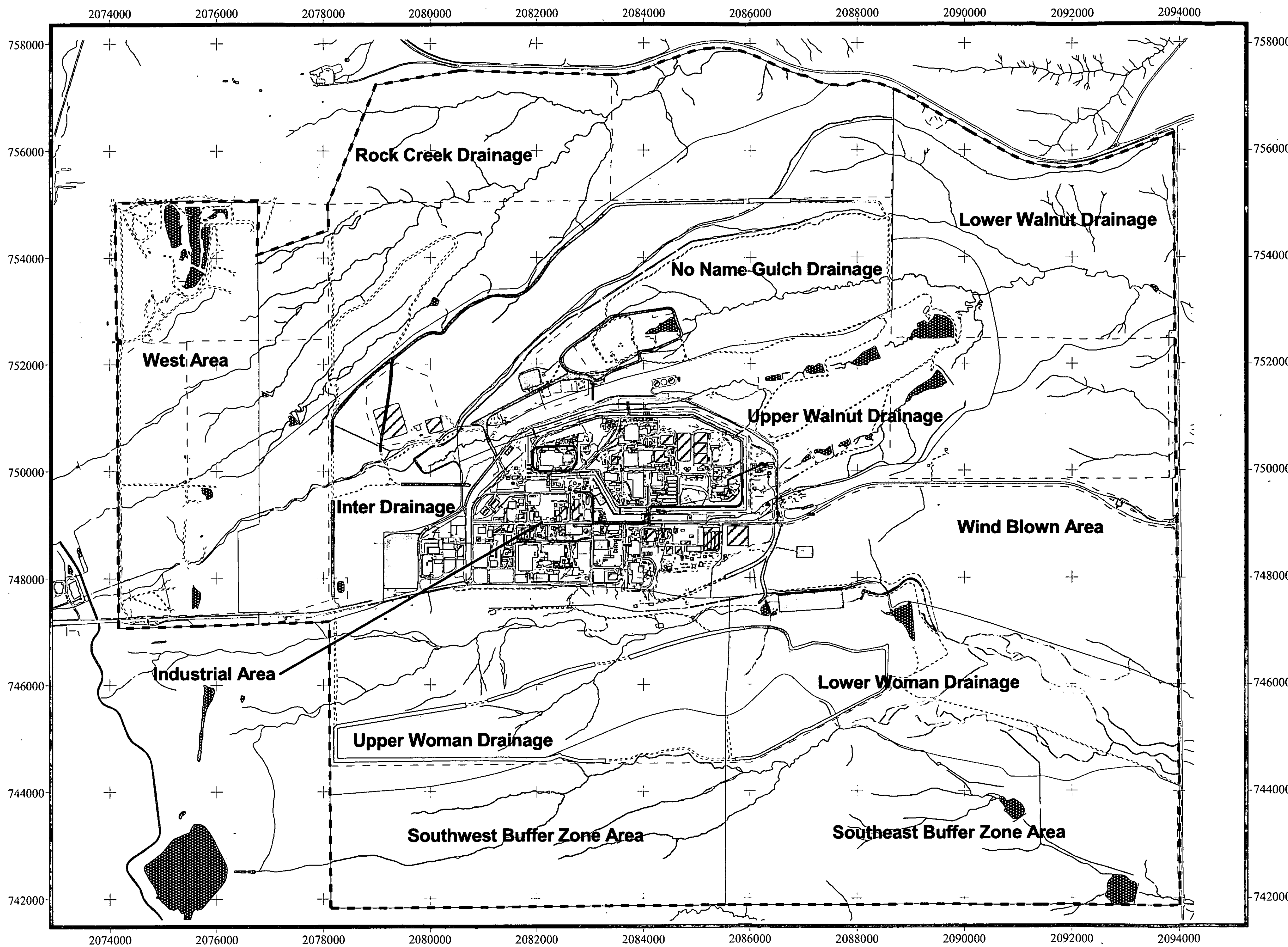

Figure 4.3 Exposure Units with PACs

KEY

- PAC
- Streams, ditches, or other drainage feature
- Paved road
- Dirt road
- Lakes and ponds
- Fence

Building

- Demolished
- Standing
- Site boundary

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N W E S

700 0 700 Feet

Scale = 1:27500

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD 27

U.S. Department of Energy
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4.2.2 Exposure Units for the Wildlife Refuge Worker

As discussed above, EUs for the WRW, shown on Figure 4.1, incorporate information on contaminant releases and watershed and drainage features, and are based on anticipated activity patterns. These EUs form the basis for the assessment of risks to the anticipated major receptor in the CRA, recognize distinct areas of contamination, and support land use planning.

The assessments for the EUs represent the risks a worker will encounter in discharging his or her duties across the Site. The nature of the work involves movement over the entire Site. Therefore, relatively small EUs do not represent true estimates of long-term risks to the worker. However, due to the nature of the distribution of residual contamination across the Site, some areas represent a greater risk to the worker. The EU assessments address this concern by representing functional areas in which the WRW will randomly contact the areas of greater risk. The EU assessments will provide a realistic evaluation of long-term risks at the Site.

The HHRA flow for each EU is given below. The flow for the ERA is provided in Section 7.

1. The areas of the EUs are set forth in this Methodology.
2. All surface soil, sediment, and subsurface soil sampling locations will be assessed at each EU for the WRW scenario.
3. A DQA will be performed on the samples in each EU to ensure that the data within each are of sufficient quantity and quality to perform a risk assessment.
4. The COC selection process will be applied to surface soil, sediments, and subsurface soil to a depth of 8 feet, the estimated depth of potential disturbance.
5. Soil below 8 feet in depth will be qualitatively evaluated.
6. Data will be aggregated by EU and risks will be characterized.

4.2.3 Exposure Units for the Wildlife Refuge Visitor

The refuge visitor is envisioned as participating in a variety of activities at the wildlife refuge. The visitor may be under the guidance and oversight of a WRW. Therefore, the same EUs will be applied to assess risks to the WRV as for the WRW.

The risk assessment flow for each WRV EU is given below:

1. The EUs are set forth in this Methodology.
2. All surface soil and sediment sampling locations in each EU will be assessed for the WRV scenario.
3. Surface soil and sediments will be combined for the COC selection process.
4. A DQA will be performed on the samples in each EU to ensure that the data within each are of sufficient quantity and quality to perform a risk assessment.

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5. Data will be aggregated by EU and risks will be characterized.

4.3 Data Aggregation for Risk Assessment

Analytical results from sampling and contaminant concentrations estimated from transport modeling that meet the DQO and DQA requirements will be used to estimate human health risks on an EU basis (Section 4.2). The types of data aggregation to be performed for the HHRA are outlined in Table 4.5. Data for surface soil, subsurface soil, and sediments will be aggregated on an EU basis to estimate exposure concentrations and intakes to perform the CRA.

Table 4.5 Data Aggregation for the CRA

Exposure Scenario	Media	Data Aggregated by EU
WRW	Surface Soil and Sediment	Yes
	Subsurface Soil[a]	Yes
WRV	Surface Soil and Sediment	Yes
	Subsurface Soil	No

a. Subsurface soil will be assessed for human health outside the ICA.

4.4 Human Health Contaminant of Concern Identification and Selection

COCs will be selected for each media and identified on an EU basis. The COC selection process is specific to the CRA and differs somewhat from that used in the determination of accelerated actions due to human health concerns. COCs will be determined for each individual EU because historical use of chemicals varied across the Site. The COC lists will be developed using the WRW PRGs or screening-level PRGs. The WRW PRGs are documented in Appendix N of Appendix 3 of RFCA (DOE et al. 1996 [as modified]). Screening-level PRGs have been developed specifically for the CRA for WRW exposure to subsurface soil, inhalation of volatiles in indoor air, and ingestion of surface water. These risk-based values will only be used for the CRA and will not be incorporated in RFCA. The screening-level PRGs are documented in Appendix A. The WRW COCs will also be used for the WRV scenario.

4.4.1 Selection of Human Health Contaminants of Concern

The selection of COCs will follow the process outlined on Figure 4.4. The process will be repeated for each EU. Environmental media that will be included in the COC selection process are surface soil, sediments, and subsurface soil.

4.4.2 Data Quality Assessment

The DQA will be conducted to assess the quality of reported data as described in Section 3.1.5. Data will be assessed on a Sitewide and EU basis, as appropriate, for the risk

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assessment to be performed. Outliers will also be assessed using standard statistical testing and eliminated, if appropriate.

4.4.3 Data Aggregation

The data will be aggregated by area (that is, Sitewide and EU), media (for example, surface soil), and analyte prior to initiation of the DQA and COC screening processes. A value of one-half the reported value will be used for all U-qualified (nondetect) inorganic and organic data (EPA 1989). This does not apply to radionuclides, for which reported values will be used in all cases. A summary presentation of the data will include:

- Chemical name;
- Chemical Abstract Service (CAS) number;
- Chemical-specific, contract-required quantitation limit (CRQL);
- Reported detection limit;
- Number of samples;
- Frequency of detection;
- Minimum detected concentration;
- Maximum detected concentration;
- Arithmetic mean concentration; and
- Standard deviation.

4.4.4 Elimination of Essential Nutrients/Major Cations and Anions

Intakes calculated based on maximum concentrations of essential nutrients in soil and sediment samples that have no toxicity values will be compared to daily reference intakes (DRIs) and upper limit daily nutrient intakes (ULs) in accordance with EPA guidance (1989). All essential nutrients that fall within the range of recommended or maximum daily intakes (NAS 2000, 2002) will be eliminated from further consideration in the CRA.

Nitrate, nitrite, ammonium, and fluoride have oral toxicological factors and will be assessed in the surface water screen. Nitrate will also be assessed in soil, due to its presence in groundwater. Sulfide, bicarbonate, bromide, carbonate, chloride, orthophosphate, and sulfate have no toxicological factors and will be eliminated from assessments in soil and sediments.

4.4.5 Preliminary Remediation Goals Screen

All remaining potential contaminants of concern (PCOCs) will be screened against the WRW PRGs presented in Appendix 3, Implementation Guidance Document, Appendix N, Preliminary Remediation Goals (DOE et al. 1996 [as modified]) and the screening-level PRGs presented in Appendix A for the appropriate media using a hazard quotient (HQ) of 0.1 or risk of 1×10^{-6}. All PCOCs with maximum values below the WRW PRGs will be eliminated for an EU. The PRG ratios for each PCOC will be presented in tables.

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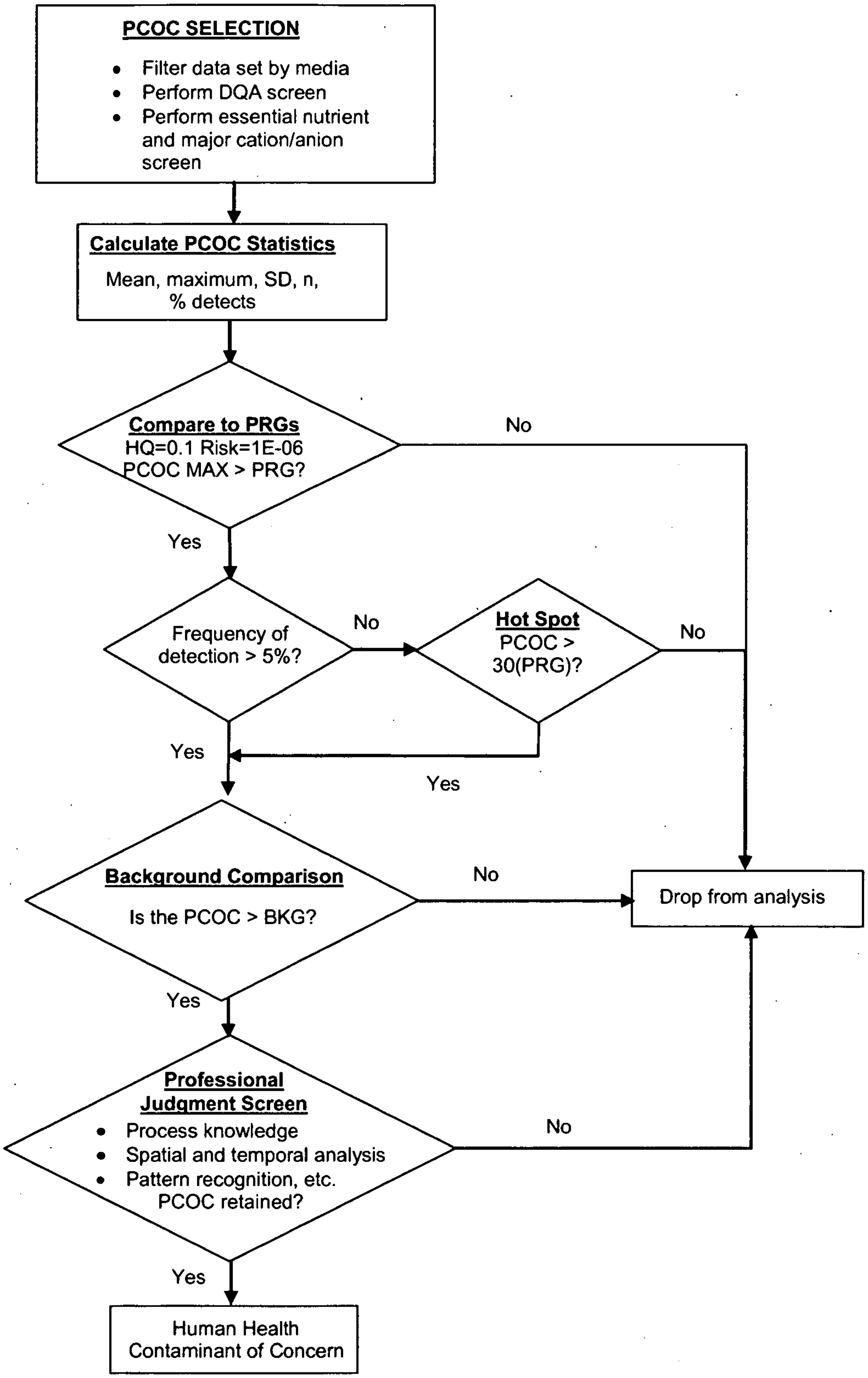
Figure 4.4 Human Health CRA COC Selection Process



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4.4.6 Detection Frequency Filter

Compounds detected at a frequency of 5 percent or greater will be carried through the COC selection process. Compounds detected at less than 5 percent frequency are not considered characteristic of Site contamination and the potential for exposure is low.

All analytes with less than 5 percent detection frequency will be compared to Site PRGs set to an HQ of 3.0 or risk of 3×10^{-5} as a health-protective precaution as agreed upon and documented in the IASAP (DOE 2001). If the maximum detected value of an infrequently detected contaminant (less than 5 percent) exceeds the screening value, it will be carried through the COC screening process.

4.4.7 Data Distribution Testing

Data distribution testing will be performed for all PCOCs retained following the PRG and frequency screens to aid in deciding the statistical test to use for comparison to background. Testing will be conducted following EPA guidance (EPA 2002a) and EPA QA/G-9 methods (EPA 2000b). The statistical tests to be used for determining data distributions are:

- Shapiro-Wilk Test (S-W) (test limited to n > or = 30 and < or = 50); and
- Shapiro-Francia Test (S-F [D'Agustino 1986]) (n > 50).

The test will be chosen based on sample size as recommended by EPA (1992d). Data sets with less than 30 samples will be considered lognormally distributed. The robustness of this assumption will be assessed and documented. If the chosen test identifies the distribution as normal, testing will stop and the data will be considered normally distributed. If not, the data will be log-transformed and tested again. The data will then be assigned a lognormal or nonparametric distribution, depending on the results. The assigned distribution will then be used to determine the appropriate test for the background comparison and estimate an appropriate upper confidence at the 95 percent level (95UCL) concentration.

4.4.8 Background Analysis

Following the determination of data distributions, inorganic and radionuclide PCOCs will be compared statistically to background data sets to determine whether the PCOCs are present at concentrations above background.

The background comparison is used to distinguish between contamination associated with Site activities and nonanthropogenic (naturally occurring) background conditions. The Geochemical Characterization of Background Surface Soils: Background Soils Characterization Program, Final Report (DOE 1995a) will be used for the surface soil background data. The Background Geochemical Characterization Report (DOE 1993) will be used for the remaining media types. Background comparisons will be performed in accordance with current EPA guidance (2002a).

The statistical test chosen for a particular PCOC depends on the distributions of the PCOC and background data. Either parametric or nonparametric tests can be used, although neither works well with small data sets of less than 25 samples (EPA 2002a). Therefore, it is important that a combination of statistical testing and other comparison methods, including graphical, 95UCLs, outlier testing, and comparison of maximum values, be used to compare

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the populations. The Wilcoxon (also known as Mann-Whitney) Rank Sum Test is useful when Site and background data have different assigned distributions or are both nonparametric (that is, not normally or lognormally distributed). If Site and background data have the same normal or lognormal distributions, a Student's t-test can be used to compare PCOCs to background. Lognormal data are log-transformed prior to conducting a standard t-test. Evaluation of 95 percent confidence intervals for Site and background data can also be useful. Overlap of 95 percent confidence intervals indicates the Site data are within the range of natural background.

If the concentrations for a particular PCOC are found to be significantly greater (alpha = 0.1, when applicable) than background levels, the PCOC will be retained for further consideration. Following the background comparison, professional judgment will be applied, as described in the next section.

4.4.9 Professional Judgment

Professional judgment is also used to include or exclude a PCOC from the final COC list. A PCOC that has been previously eliminated may be included because of a preponderance of historical data suggesting the chemical may have been released in significant quantities to the environment. Professional judgment can also be applied to develop a weight of evidence argument to exclude a PCOC based on data assessment, or spatial, temporal, or pattern-recognition concepts. All such decisions will be documented in the CRA Report.

Data assessment includes an evaluation of laboratory and validation qualifiers. Spatial analysis requires that concentrations of each PCOC be plotted on a map; assessment of the plotted data should indicate their presence (or absence) or any trends in concentration, and assist in delimiting hot spots.

Temporal analysis is particularly relevant for groundwater data, where repeated sampling at a well offers the opportunity to evaluate changes in analyte concentrations over time. Time-series plots are used for this evaluation. Temporal analysis of data for sediments or other geologic materials is less useful and may not even be applicable.

Pattern recognition includes:

- Interelement correlations;
- Similarities in geochemical behavior;
- Correlations between elemental concentrations and certain parameters such as total suspended solids (TSS), the negative logarithm of the hydrogen ion activity (pH), reduction-oxidation potential (standard reduction potential [volts] [Eh] or negative logarithm of the electron activity [Pe], where Eh=0.059*Pe), clay content, organic content, cation-exchange capacity, and so forth; and
- Other recognizable patterns in elemental behavior.

Professional judgment will be applied on a case-by-case basis. All such judgment will be supported by a thorough analysis of the available evidence. Documentation, including maps, figures, and references supporting the professional judgment, will be presented.

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4.4.10 Presentation of Contaminants of Concern

The COC selection process will be documented in tables, such as Table 4.6, that will summarize the data for each analyte chosen as a COC in each medium.

Table 4.6 Rationale for Selecting COCs

Analyte	PRG Ratio	Detection Frequency (%)	> 30X the PRG?	Background Comparison	Professional Judgment	COC?

4.5 Pathway Significance Evaluations

Two pathways for the WRW are currently considered to have insignificant contributions to risk:

- Ingestion of contaminants transported from groundwater to surface water; and
- Inhalation of contaminants volatilizing from groundwater and soil outside the ICA.

Evaluations will be completed to ensure that the designation as insignificant is appropriate. The evaluations are described below.

4.5.1 Groundwater-to-Surface Water Pathway

In the WRW scenario, the worker is potentially exposed to contaminants in surface water by ingestion while working. This pathway is currently considered insignificant. If contaminants known to be present in groundwater are transported to surface water in sufficient concentrations, this pathway could become a significant contributor to risk. The results of groundwater transport modeling can resolve this issue. Groundwater modeling for the Site is being conducted for a variety of purposes, one of which is to support the CRA. The objective of the transport modeling in support of the CRA is to simulate transport of contaminants from groundwater to surface water, and estimate future exposure concentrations in surface water for potential on-site receptors. A subsurface water transport model is under development to estimate surface water concentrations for the analytes selected by a screening procedure, using surface water PRGs developed for WRW (Appendix A) and ecological receptor (DOE et al. 1996 [as modified]) exposures to surface water.

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The estimated concentrations at select surface water locations will be subjected to the COC selection process in the CRA. Results will be used to estimate potential human health or ecological effects from surface water concentrations resulting from the transport of contaminants currently in groundwater. The transport model will be calibrated using available information on contaminant sources, current contaminant distributions, and historical concentrations over time. DQOs for the modeling effort will accompany its documentation.

4.5.2 Groundwater/Subsurface Soil-to-Air Pathway

In the WRW scenario, the worker is potentially exposed to contaminants in groundwater that volatilize and are transported through the soil and released to the atmosphere, where they can be inhaled by the worker. Exposure to volatilized contaminants can occur indoors or outdoors. These pathways are both currently considered insignificant. The indoor route is considered a greater contributor to risk due to inhibited air exchange in buildings. If contaminants known to be present in groundwater are transported to the soil surface and then to the atmosphere in sufficient concentrations, the indoor pathway could become a significant contributor to risk. Indoor air exposures will be assessed for areas outside the ICA (Section 2.2.1). The groundwater/subsurface soil air pathway for volatiles will be assessed outside the ICA. The COCs to be assessed will be chosen using the PRGs presented in Appendix A.

4.6 Exposure Point Concentrations and Intakes

The EPC of a human health COC in a sampled medium is often quantified using the 95UCL on the arithmetic mean (EPA 1989). This approach ignores any sampling bias toward areas of known or suspected contamination and treats the data as if they were randomly collected. At RFETS the majority of the sampling effort has targeted IHSSs, PACs and other areas with suspected releases. This unequal sampling density is not compatible with the problem statement in Section 3.1.1 that states long-term average exposures in an EU must be estimated. In areas with biased sampling the arithmetic mean is a worst-case or upper-bound estimate on risk. Geospatial techniques can be used to correct for the bias in sampling. Therefore, a three-tiered approach, as presented below, will be used to calculate EPCs for the HHRA. The results of both approaches will be presented in the exposure assessment and the risk characterization.

Tier 1: Mean Concentrations

The arithmetic mean is a statistically robust estimator, even when normality assumptions are not met (Gilbert 1987). The 95UCL is a conservative estimate of the average concentration to which receptors would be exposed over time in an exposure area. If the maximum detected COC value is below the 95UCL, the maximum concentration is used as the EPC. When data distributions are demonstrated to be lognormal, an arithmetic mean and 95UCL will be calculated using log-transformed data. When distributions are found to be neither normal nor lognormal, a nonparametric 95UCL will be calculated (EPA 2002b).

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Tier 2: Area Averaging

The geospatial technique of area averaging will also be used to provide a more realistic estimate of health risks and hazards. This approach is simple and easy to implement, will very likely yield much more realistic estimates of the true mean, and it is expected that 95UCLs generated in this way will minimize the risk of Type I errors.

The Tier 2 approach will be implemented in four steps for the HHRA:

1. A 30-acre grid will be randomly laid over the Site or EU.
2. The mean value will be calculated for each 30-acre cell, using all relevant samples from within the cell.
3. The grid means will be used to calculate the best estimate of the mean for the EU as an area-weighted average.
4. The uncertainty around the best estimate of the mean will be estimated using the same method as for Tier 1. The 95UCL of the EU area-weighted mean will be used as the EPC.

Tier 3: Kriging

This geostatistical method, developed for the mining industry, is a more robust and statistically valid approach for estimating values and uncertainty around key statistics (mean, 90th percentile) than area averaging. Kriging can account accurately for the uneven spatial distribution of samples. However, various parameters developed for a specific application are subject to debate among experts. Therefore, this approach will be implemented only as needed after an initial analysis using Tiers 1 and 2.

4.6.1 Exposure Point Concentration Calculation

The one-sided 95UCL will be calculated using the Student's t-statistic and will be used for normally distributed data with 30 or more samples (Gilbert 1987). EPA guidance (2002b) contains recommendations for several calculation methods for lognormally distributed data. Rather than use a battery of tests, the Chebychev inequality method for calculation of the 95UCL has been chosen due to its versatility. The Chebychev method will be used for all lognormally distributed data and for data sets with less than 30 samples.

A Bootstrap nonparametric, probabilistic resampling methodology will be used to determine the 95UCL when observed data are not normally or lognormally distributed and have 30 or more samples. Bootstrap calculations of the 95UCL avoid difficulties associated with empirically determining the shape of the observed distribution because it has no distributional assumptions. This resampling technique provides estimates of the mean and variance for any distribution regardless of the specific shape and "performs substantially better, sometimes orders of magnitude better, in estimating the 95UCL of the mean from positively skewed data sets" than other methods (EPA 1997). A normal Bootstrap program will be used to derive all mean and variance estimates. The Bootstrap method will be used to calculate EPC terms for estimating risk, as presented in EPA guidance (2002b). Estimates derived for the CRA will be developed using 2,000 or more resampling events. Use of 1,000

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iterations has been demonstrated to be sufficient for estimating the mean and associated variance (DOE 2003a).

EPCs will be estimated at human receptor locations for all pertinent environmental media, including surface and subsurface soil and sediments. The physical, chemical, and hydrogeologic characteristics of the Site must therefore be adequately studied and understood. Steady-state conditions will be assumed for EPCs based on direct environmental monitoring data. Effects of dilution, dispersion, source-term depletion, erosion, biodegradation, and sorption on quantification of the EPCs will be addressed in the uncertainty section of the CRA. EPCs will be estimated to realistically predict long-term averages and impacts to receptors.

EPCs for human receptors will be determined using measured environmental monitoring data. Subsurface soil concentrations will be used to estimate source terms for the possible transport of contaminants to groundwater and surface water locations and subsequent direct ingestion by human receptors.

4.6.2 Intake Calculations

Intake by receptors will be quantified for each selected COC, exposure pathway, and exposure scenario. Exposure factors reported in Section 4.1 will be used in the CRA. Intake in units of mg/kg per day will be calculated for all receptors exposed to ingestion, dermal, and inhalation pathways using the general formulas below. Radiological intake in units of picocuries (pCi) will be assessed using the standard EPA formulas. External radionuclide exposure is calculated in units of years per picocurie per gram (yr/pCi/g).

The equations for calculating intakes for the WRW and WRV are provided in Tables 4.7 and 4.8. The abbreviations and specific values used for the exposure factors are defined in Tables 4.1 and 4.2.

Intakes are averaged over different time periods for carcinogenic and noncarcinogenic chemicals. For carcinogens, intakes are calculated by averaging the total cumulative dose during the exposure period over a lifetime, yielding a "lifetime average daily intake" (EPA 1989). For noncarcinogenic chemicals, intakes are calculated by averaging over the period of exposure to yield an average daily intake. Different averaging times are used for carcinogens and noncarcinogens because their effects occur by different mechanisms. The approach for carcinogens is based on the hypothesis that a high dose received over a short period of time is equivalent to a corresponding low dose spread over a lifetime. The intake of a carcinogen is averaged over a 70-year lifetime regardless of exposure duration.

For calculation of radionuclide intakes, the exposure concentration is expressed in picocuries per liter (pCi/L), and the expression is not divided by body weight or averaging time. The resulting intake for radionuclides is expressed in pCi.

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Table 4.7 Intake Equations for the WRW

Wildlife Refuge Worker[a]
Surface Soil and Sediment Intake Equations
Intake Equations for WRW Ingestion
Nonradionuclide Intake (mg/kg-day) = $\frac{\text{Cs x IRwss x EFwss x EDw x CF1}}{\text{BWa x [ATc or ATnc]}^{b}}$
Radionuclide Intake (pCi) = Cs x IRwss x EFwss x EDw x CF3
Intake Equation for WRW Dermal Contact
Nonradionuclide Intake (mg/kg-day) = $\frac{\text{Cs x EFwss x EDw x EVw x SAw x AFw x ABS x CF1}}{\text{BWa x [ATc or ATnc]}^{b}}$
Intake Equations for WRW Outdoor Inhalation of Suspended Particulates
Nonradionuclide Intake (mg/kg-day) = $\frac{\text{Cs x IRaw x EFwss x EDw x ETw x ETo\_w x MLF}}{\text{BWa x [ATc or ATnc]}^{b}}$
Radionuclide Intake (pCi) = Cs x IRaw x EFwss x EDw x ETw x ETo_w x MLF x CF2
Intake Equations for WRW Indoor Inhalation of Suspended Particulates
Nonradionuclide Intake (mg/kg-day) = $\frac{\text{Cs x IRaw x EFwss x EDw x ETw x ETi\_w x DFi x MLF}}{\text{BWa x [ATc or ATnc]}^{b}}$
Radionuclide Intake (pCi) = Cs x IRaw x EFwss x EDw x ETw x ETi_w x DFi x MLF x CF2
Exposure Equation for WRW Outdoor External Radiation
Radionuclide Exposure (yr*pCi/g) = Cs x Te_A x Te_Do x EDw x ACF x GSFo
Exposure Equation for WRW Indoor External Radiation
Radionuclide Exposure (yr*pCi/g) = Cs x Te_A x Te_Di x EDw x ACF x GSFi
Subsurface Soil Intake Equations
Intake Equations for WRW Ingestion
Nonradionuclide Intake (mg/kg-day) = $\frac{\text{Cs x IRwss x EFwsub x EDw x CF1}}{\text{BWa x [ATc or ATnc]}^{b}}$
Radionuclide Intake (pCi) = Cs x IRwss x EFwsub x EDw x CF3
Intake Equation for WRW Dermal Contact
Nonradionuclide Intake (mg/kg-day) = $\frac{\text{Cs x EFwsub x EDw x EVw x SAw x AFw x ABS x CF1}}{\text{BWa x [ATc or ATnc]}^{b}}$
Intake Equations for WRW Outdoor Inhalation of Suspended Particulates
Nonradionuclide Intake (mg/kg-day) = $\frac{\text{Cs x IRaw x EFwsub x EDw x ETw x ETo\_w x MLF}}{\text{BWa x [ATc or ATnc]}^{b}}$
Radionuclide Intake (pCi) = Cs x IRaw x EFwsub x EDw x ETw x ETo_w x MLF x CF2
Exposure Equation for WRW Outdoor External Radiation
Radionuclide Exposure (yr*pCi/g) = Cs x Te_As x Te_Do x EDw x ACF x GSFo

a. Definitions of abbreviations can be found in Table 4.1.

b. Carcinogenic (ATc) or noncarcinogenic (ATnc) averaging times are used in equations, depending on whether carcinogenic or noncarcinogenic intakes are being calculated.

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Table 4.8 Intake Equations for the WRV

Wildlife Refuge Visitor[a]
Intake Equations for WRV Ingestion of Soil
Nonradionuclide Intake (mg/kg-day) = (Cs x SIRageav x EFv x CF1) / [ATc or ATnc][b]
Radionuclide Intake (pCi) = Cs x SIRagav_r x EFv x EDt x CF3 units
Intake Equation for WRV Dermal Contact with Soil
Nonradionuclide Intake (mg/kg-day) = (Cs x EFv x EVv x SFSagav x ABS x CF1) / [ATc or ATnc][b]
Intake Equations for WRV Inhalation of Surface Soil
Nonradionuclide Intake (mg/kg-day) = (Cs x IRagav x EFv x MLF) / [ATc or ATnc][b]
Radionuclide Intake (pCi) = Cs x Iragav_r x EFv x (EDav + EDcv) x ETv x MLF x CF2
Exposure Equation for WRV External Radiation from Surface Soil
Radionuclide Intake (yr*pCi/g) = Cs x Te_Av x Te_Dv x ACF x GSFo

a. Definitions of abbreviations can be found in Table 4.2.
b. Carcinogenic (ATc) or noncarcinogenic (ATnc) averaging times are used in equations, depending on whether carcinogenic or noncarcinogenic intakes are being calculated.

5.0 HUMAN HEALTH TOXICITY ASSESSMENT

Toxicity values are used to characterize risk, while toxicity profiles summarize toxicological information for radioactive and nonradioactive COCs. Toxicity information is summarized for two categories of potential effects: noncarcinogenic and carcinogenic. These two categories have slightly differing methodologies for estimating potential health risks associated with exposures to carcinogens and noncarcinogens.

In general, toxicity profiles are obtained from EPA's Integrated Risk Information System (IRIS). IRIS contains only those toxicity values that have been verified and undergone extensive peer review by EPA's Reference Dose or Carcinogenic Risk Assessment Verification Endeavor (CRAVE) workgroups. The IRIS database is updated monthly and supercedes all other sources of toxicity information.

The CRA generally uses the recommended hierarchy of toxicological sources of information as recommended by EPA (EPA 2003a). The recommended toxicity value hierarchy is as follows:

- Tier 1 - EPA's IRIS (EPA 2004)
- Tier 2 - EPA's Provisional Peer Reviewed Toxicity Values (PPRTVs) – The Office of Research and Development/National Center for Environmental Assessment (NCEA)/Superfund Health Risk Technical Support Center (STSC) develops PPRTVs on a chemical-specific basis when requested by EPA's Superfund program.
- Tier 3 - Other Toxicity Values – Tier 3 includes additional EPA and non-EPA sources of toxicity information. Priority is given to those sources of information that are the most current, the basis for which is transparent and publicly available, and which have been peer reviewed. Consensus will be sought on all toxicity values used in the CRA.

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Secondary sources of information will be used qualitatively in the HHRA. EPA toxicologists, both regional and national, may also serve as information sources. All information sources will be documented in the toxicity assessment. In general, the toxicity factors used for the Site PRGs will be used in the CRA, unless updates become available.

5.1 Identification of Toxicity Values for Carcinogenic Effects

Potential carcinogenic risks will be expressed as an estimated probability that an individual might develop cancer from lifetime exposure. This probability is based on projected intakes and chemical-specific dose-response data called "cancer slope factors (CSFs)." CSFs and the estimated daily intake of a compound, averaged over a lifetime, are used to estimate the incremental risk that an individual exposed to that compound may develop cancer. There are two classes of potential carcinogens: chemical carcinogens and radionuclides.

5.1.1 Chemical Carcinogens

Evidence of chemical carcinogenicity originates primarily from two sources: lifetime studies with laboratory animals and human (epidemiological) studies. Animal data from laboratory experiments represent the primary basis for the extrapolation for most chemical carcinogens. Experimental results are extrapolated across species (that is, from laboratory animals to humans); from high-dose regions (that is, levels to which laboratory animals are exposed) to low-dose regions (that is, levels to which humans are likely to be exposed in the environment); and across routes of administration (for example, inhalation versus ingestion).

EPA estimates human cancer risks associated with exposure to chemical carcinogens on an administered-dose basis. It is assumed a small number of molecular events can evoke changes in a single cell that can lead to uncontrolled cellular proliferation and tumor induction. This mechanism for carcinogenesis means there is theoretically no level of exposure to a given chemical carcinogen that does not pose a small, but finite, probability of generating a carcinogenic response.

The CSFs are estimated using the linearized multistage model. The basis of this model is that multiple events may be needed to yield tumor induction (Crump et al. 1977) reflecting the biological variability in tumor frequencies observed in animal and human studies. The dose-response relationship predicted by this model at low doses is essentially linear. The CSFs calculated for nonradiological carcinogens using the multistage model represent the 95UCL of the probability of a carcinogenic response. Consequently, risk estimates based on these CSFs are conservative estimates representing upper-bound estimates of risk.

Uncertainties in the toxicity assessment for chemical carcinogens are dealt with by classifying each chemical into one of several groups, according to the EPA-defined, weight-of-evidence from epidemiological studies and animal studies. These groups are listed in Table 5.1.

Table 5.1 Carcinogen Groups

Weight-of-Evidence Group	Description
A	Human carcinogen (sufficient evidence of carcinogenicity in humans)
B	Probable human carcinogen (B1 - limited evidence of carcinogenicity in humans; B2 - sufficient evidence of carcinogenicity in animals with inadequate or lack of evidence in humans)
C	Possible human carcinogen (limited evidence of carcinogenicity in animals and inadequate or lack of human data)
D	Not classifiable as to human carcinogenicity (inadequate or no evidence)
E	Evidence of noncarcinogenicity in humans (no evidence of carcinogenicity in adequate studies)

The oral and inhalation CSFs for the COCs will be compiled in a table. Table 5.2 presents the current CSFs used for calculation of the PRGs. These values will be updated as part of the RFCA annual review and incorporated into the CRA. A similar table of values will be included in the CRA.

5.1.2 Radionuclides

A series of federal guidance documents have been issued by EPA for the purpose of providing federal and state agencies with technical information to assist their implementation of radiation protection programs. The Health Effects Assessment Summary Tables (HEAST) for Radionuclides (EPA 2001a) provides numerical factors, called "risk coefficients," for estimating risks to health from exposure to radionuclides. This federal guidance will be used to calculate risk from radionuclides. It applies state-of-the-art methods and models that take into account age and gender dependence on intake, metabolism, dosimetry, radiogenic risk, and competing causes of death in estimating the risks to health from internal or external exposure to radionuclides.

A morbidity risk coefficient is provided for a given radionuclide and exposure mode. This coefficient is an estimate of the average total risk of experiencing a radiogenic cancer, regardless of whether the cancer is fatal. The risk coefficient associated with morbidity will be used to characterize human health risks. Current values used are shown in Table 5.3.

5.2 Identification of Toxicity Values for Noncarcinogenic Effects

Potential noncarcinogenic effects will be evaluated in the risk characterization by comparing daily intakes (calculated in the exposure assessment) with chronic reference doses (RfDs) developed by EPA. A chronic RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of the daily exposure that can be incurred during a lifetime, without an appreciable risk of a noncarcinogenic effect being incurred in human populations, including sensitive subgroups (EPA 1989). The RfD is based on the assumption that thresholds exist for noncarcinogenic toxic effects (for example, liver or kidney damage). Adverse effects are not expected to occur with chronic daily intakes below the RfD value.

Table 5.2 Nonradiological Toxicity Constants

Target Analyte List Chemical[1]		CAS Number	Oral RfD (mg/kg-day)		Oral/Ingestion Slope Factor (mg/kg-day)-1		Inhalation RfD (mg/kg-day)		Inhalation Slope Factor (mg/kg-day)-1		Dermal ABS[2] Fraction Absorbed
Acenaphthene	(V)	83-32-9	0.06	I							0.13
Acetone	(V)	67-64-1	0.1	I							
Aldrin		309-00-2	0.00003	I	17	I			17	I	0.1
Aluminum		7429-90-5	1	E			0.001	E			
Anthracene	(V)	120-12-7	0.3	I							0.13
Antimony		7440-36-0	0.0004	I							
Aroclor-1016		12674-11-2	0.00007	I	0.07	I			0.07	Ia	0.14
Aroclor-1221		11104-28-2			2	Ia			0.4	Ia	0.14
Aroclor-1232		11141-16-5			2	Ia			0.4	Ia	0.14
Aroclor-1242		53469-21-9			2	Ia			0.4	Ia	0.14
Aroclor-1248		12672-29-6			2	Ia			0.4	Ia	0.14
Aroclor-1254		11097-69-1	0.00002	I	2	Ia			0.4	Ia	0.14
Aroclor-1260		11096-82-5			2	Ia			0.4	Ia	0.14
Arsenic		7440-38-2	0.0003	I	1.5	I			15.05	I	0.03
Barium		7440-39-3	0.07	I			0.0001429	A			
Benzene	(V)	71-43-2	0.003	E	0.055	I	0.0017	E	0.029	I	
alpha-BHC		319-84-6			6.3	I			6.3	I	0.04
beta-BHC		319-85-7			1.8	I			1.8	I	0.04
delta-BHC		319-86-8									0.04
gamma-BHC (Lindane)		58-89-9	0.0003	I	1.3	H					0.04
Benzo(a)anthracene		56-55-3			0.73	E					0.13
Benzo(a)pyrene		50-32-8			7.3	I			0.31	E	0.13
Benzo(b)fluoranthene		205-99-2			0.73	E					0.13
Benzo(k)fluoranthene		207-08-9			0.073	E					0.13
Benzoic Acid (at pH 7)		65-85-0	4	I							
Benzyl Alcohol		100-51-6	0.3	H							
Beryllium		7440-41-7	0.002	I			5.71E-06	I	8.4	I	
bis(2-chloroethyl)ether	(V)	111-44-4			1.1	I			1.1	I	
bis(2-chloroisopropyl)ether	(V)	39638-32-9	0.04	I	0.07	H			0.035	H	

Table 5.2 Nonradiological Toxicity Constants

Target Analyte List Chemical[1]		CAS Number	Oral RfD (mg/kg-day)		Oral/Ingestion Slope Factor (mg/kg-day)$^{-1}$		Inhalation RfD (mg/kg-day)		Inhalation Slope Factor (mg/kg-day)$^{-1}$		Dermal ABS[2] Fraction Absorbed
bis(2-ethylhexyl)phthalate		117-81-7	0.02	I	0.014	I			0.014	E	0.1
Bromodichloromethane	(V)	75-27-4	0.02	I	0.062	I					
Bromoform	(V)	75-25-2	0.02	I	0.0079	I			0.0039	I	
Bromomethane (methyl bromide)	(V)	74-83-9	0.0014	I			0.0014286	I			
2-Butanone (methyl ethyl ketone)	(V)	78-93-3	0.6	I			0.2857143	I			
Butylbenzylphthalate		85-68-7	0.2	I							0.1
Cadmium (water)		7440-43-9	0.0005	I					6.3	I	
Cadmium (food)		7440-43-9	0.001	I			0.000057	E	6.3	I	0.001
Carbon disulfide	(V)	75-15-0	0.1	I			0.2				
Carbon tetrachloride	(V)	56-23-5	0.0007	I	0.13	I	0.000571	E	0.053	I	
alpha-Chlordane		5103-71-9	0.0005	I	0.35	I	0.0002	b	0.35	b	0.04
beta-Chlordane		5103-74-2	0.0005	I	0.35	I	0.0002	b	0.35	b	0.04
gamma-Chlordane		12789-03-6	0.0005	I	0.35	I	0.0002	b	0.35	b	0.04
4-Chloroaniline		106-47-8	0.004	I							0.1
Chlorobenzene	(V)	108-90-7	0.02	I			0.017	E			
Chloroethane (ethyl chloride)	(V)	75-00-3	0.4	E	0.0029	E	2.8571429	I			
Chloroform	(V)	67-66-3	0.01	I			0.000086	E	0.0805	I	
Chloromethane (methyl chloride)	(V)	74-87-3			0.013	H	0.026	I	0.0035	E	
2-Chloronaphthalene	(V)	91-58-7	0.08	I							
2-Chlorophenol	(V)	95-57-8	0.005	I							
Chromium III		16065-83-1	1.5	I							
Chromium VI		18540-29-9	0.003	I			0.00003	H	41	H	
Chrysene		218-01-9			0.0073	E			0.0031	E	0.13
Cobalt		7440-48-4	0.02	E			0.0000057	E			
Copper		7440-50-8	0.04	H							
Cyanide		57-12-5	0.02	I							
4,4-DDD		72-54-8			0.24	I					0.03
4,4-DDE		72-55-9			0.34	I					0.03
4,4-DDT		50-29-3	0.0005	I	0.34	I			0.3395	I	0.03

Table 5.2 Nonradiological Toxicity Constants

Target Analyte List Chemical[1]		CAS Number	Oral RfD (mg/kg-day)		Oral/Ingestion Slope Factor (mg/kg-day)$^{-1}$		Inhalation RfD (mg/kg-day)		Inhalation Slope Factor (mg/kg-day)$^{-1}$		Dermal ABS[2] Fraction Absorbed
Dibenz(a,h)anthracene		53-70-3			7.3	E			3.1	E	0.13
Dibenzofuran		132-64-9	0.004	E							0.1
Dibromochloromethane		124-48-1	0.02	I	0.084	I					0.1
Di-n-butylphthalate		84-74-2	0.1	I							0.1
1,2-Dichlorobenzene (o-)	(V)	95-50-1	0.09	I			0.04	H			
1,4-Dichlorobenzene (p-)	(V)	106-46-7	0.03	E	0.024	H	0.23	I	0.022	E	
3,3-Dichlorobenzidine		91-94-1			0.45	I					0.1
1,1-Dichloroethane	(V)	75-34-3	0.1	H			0.1428571	A			
1,2-Dichloroethane	(V)	107-06-2	0.03	E	0.091	I	0.0014	E	0.091	I	
1,1-Dichloroethene	(V)	75-35-4	0.009	I	0.6	I			0.175	I	
1,2-Dichloroethene (total)	(V)	540-59-0	0.009	H							
2,4-Dichlorophenol (at pH 6.8)		120-83-2	0.003	I							
1,2-Dichloropropane	(V)	78-87-5			0.068	H	0.0011429	I			
cis-1,3-Dichloropropene	(V)	10061-01-5	0.03	Ic	0.1	I	0.0057143	Ic	14	Ic	
trans-1,3-Dichloropropene	(V)	10061-02-6	0.03	Ic	0.1	I	0.0057143	Ic	14	Ic	
Dieldrin		60-57-1	0.00005	I	16	I			16	I	0.1
Diethylphthalate		84-66-2	0.8	I							0.1
2,4-Dimethylphenol	(V)	105-67-9	0.02	I							
Dimethylphthalate		131-11-3	10	W							0.1
4,6-Dinitro-2-methylphenol (4,6-dinitro-o-cresol)	(V)	534-52-1	0.001	E							
2,4-Dinitrophenol		51-28-5	0.002	I							
2,4-Dinitrotoluene		121-14-2	0.002	I	0.68	I					
2,6-Dinitrotoluene		606-20-2	0.001	H	0.68	I					
Di-n-octylphthalate		117-84-0	0.02	H					0.014	E	0.1
Endosulfan I		959-98-8	0.006	I							0.1
Endosulfan II		33213-65-9	0.006	I							0.1
Endosulfan sulfate		1031-07-8	0.006	I							0.1
Endosulfan (technical)		115-29-7	0.006	I							0.1

Table 5.2 Nonradiological Toxicity Constants

Target Analyte List Chemical[1]		CAS Number	Oral RfD (mg/kg-day)		Oral/Ingestion Slope Factor (mg/kg-day)$^{-1}$		Inhalation RfD (mg/kg-day)		Inhalation Slope Factor (mg/kg-day)$^{-1}$		Dermal ABS[2] Fraction Absorbed
Endrin (technical)		72-20-8	0.0003	I							0.1
Ethylbenzene	(V)	100-41-4	0.1	I			0.2857143	I	0.00385	E	
Fluoranthene		206-44-0	0.04	I							0.13
Fluorene	(V)	86-73-7	0.06	I							0.13
Heptachlor		76-44-8	0.0005	I	4.5	I			4.5	I	0.1
Heptachlor epoxide		1024-57-3	0.000013	I	9.1	I			9.1	I	0.1
Hexachlorobenzene		118-74-1	0.0008	I	1.6	I			1.6	I	0.1
Hexachlorobutadiene		87-68-3	0.0002	H	0.078	I			0.078	I	0.1
Hexachlorocyclopentadiene		77-47-4	0.006	I			0.000057	I			0.1
Hexachloroethane		67-72-1	0.001	I	0.014	I			0.014	I	0.1
Indeno(1,2,3-cd)pyrene		193-39-5			0.73	E					0.13
Iron		7439-89-6	0.3	E							
Isophorone		78-59-1	0.2	I	0.00095	I					0.1
Lead		7439-92-1									
Lithium		7439-93-2	0.02	E							
Magnesium		7439-95-4									
Manganese (Nonfood)		7439-96-5	0.02	I			1.429E-05	I			
Mercury (elemental)		7439-97-6					0.000086	I			
Methoxychlor		72-43-5	0.005	I							
Methylene chloride (dichloromethane)	(V)	75-09-2	0.06	I	0.0075	I	0.8571429	H	0.001645	I	
2-Methylnaphthalene	(V)	91-57-6	0.02	E							
4-Methyl-2-pentanone (methyl isobutyl ketone)	(V)	108-10-1	0.08	H			0.0229	H			
2-Methylphenol (o-cresol)		95-48-7	0.05	I							0.1
4-Methylphenol (p-cresol)		106-44-5	0.005	H							0.1
Molybdenum		7439-98-7	0.005	I							
Naphthalene	(V)	91-20-3	0.02	I			0.0009	I			0.1
Nickel (soluble)		7440-02-0	0.02	I							
2-Nitroaniline		88-74-4					0.0000571	H			

Table 5.2 Nonradiological Toxicity Constants

Target Analyte List Chemical[1]		CAS Number	Oral RfD (mg/kg-day)		Oral/Ingestion Slope Factor (mg/kg-day)-1		Inhalation RfD (mg/kg-day)		Inhalation Slope Factor (mg/kg-day)-1		Dermal ABS[2] Fraction Absorbed
Nitrobenzene	(V)	98-95-3	0.0005	I			0.0004	A			
4-Nitrophenol	(V)	100-02-7	0.008	E							
n-Nitrosodiphenylamine	(V)	86-30-6			0.0049	I					
n-Nitrosodipropylamine		621-64-7			7	I					
Pentachlorophenol		87-86-5	0.03	I	0.12	I					0.25
Phenol		108-95-2	0.6	I							
Pyrene		129-00-0	0.03	I							0.1
Selenium		7782-49-2	0.005	I							
Silver		7440-22-4	0.005	I							
Strontium		7440-24-6	0.6	I							
Styrene	(V)	100-42-5	0.2	I			0.2857143	I			
1,1,2,2-Tetrachloroethane	(V)	79-34-5	0.06	E	0.2	I			0.2	I	
Tetrachloroethene	(V)	127-18-4	0.01	I	0.052	E			0.00203	I	
Tin		7440-31-5	0.6	H							
Toluene	(V)	108-88-3	0.2	I			0.1142857	I			
Toxaphene		8001-35-2			1.1	I		I	1.1		0.1
1,2,4-Trichlorobenzene	(V)	120-82-1	0.01	I			0.0571	H			
1,1,1-Trichloroethane	(V)	71-55-6	0.28	E			0.63	E			
1,1,2-Trichloroethane	(V)	79-00-5	0.004	I	0.057	I			0.056	I	
Trichloroethene	(V)	79-01-6	0.0003	E	0.4	E	0.01	E	0.4	E	
2,4,5-Trichlorophenol		95-95-4	0.1	I							
2,4,6-Trichlorophenol		88-06-2			0.011	I			0.01	I	
Uranium (soluble salts)		No CASN	0.003	I							
Vanadium		7440-62-2	0.007	H							
Vinyl acetate		108-05-4	1	H			0.0571429	I			
Vinyl chloride	(V)	75-01-4	0.003	I	0.72	I	0.028	I	0.0154	I	
Xylene (total)	(V)	1330-20-7	2	I							
Zinc		7440-66-6	0.3	I							

Table 5.2 Nonradiological Toxicity Constants

Target Analyte List Chemical[1]		CAS Number	Oral RfD (mg/kg-day)		Oral/Ingestion Slope Factor (mg/kg-day)$^{-1}$		Inhalation RfD (mg/kg-day)		Inhalation Slope Factor (mg/kg-day)$^{-1}$		Dermal ABS[2] Fraction Absorbed
Nitrate		14797-55-8	1.6	I							
Nitrite		14797-65-0	0.1	I							
Ammonium (as Ammonia)		7664-41-7					0.0286	I			
Fluoride (as fluorine)		7782-41-4	0.06	I							

1. Only those constituents in ALF are included.
2. Source: EPA 2001b.

I = IRIS (EPA 2004) H = HEAST (EPA 2001a) A = HEAST Alternate; W = Withdrawn from IRIS or HEAST;
E = EPA-NCEA provisional value
(V) = Chemicals listed are volatile.
a = Values given are for PCBs.
b = Values given are for chlordane (CAS No. 12789-03-6).
c = Values given are for 1,3-dichloropropene.

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Table 5.3 Radiological Toxicity Constants

Target Analyte List Chemical	CAS Number	Oral RfD (mg/kg-day)	Soil Ingestion Oral Slope Factor (Risk/pCi)	Water Ingestion Oral Slope Factor (Risk/pCi)	Food Ingestion Oral Slope Factor (Risk/pCi)	Inhalation Slope Factor (Risk/pCi)	External Slope Factor (Risk/yr/pCi/g)
Am-241	14596-10-2		2.17E-10	1.04E-10	1.34E-10	2.81E-08	2.76E-08
Pu-239	15117-48-3		2.77E-10	1.35E-10	1.74E-10	3.33E-08	2.00E-10
Pu-240	14119-33-6		2.77E-10	1.35E-10	1.74E-10	3.33E-08	6.98E-11
U-233	13968-55-3	3.00E-03	1.6E-10	7.18E-11	9.69E-11	1.16E-08	9.82E-10
U-234	13966-29-5	3.00E-03	1.58E-10	7.07E-11	9.55E-11	1.14E-08	2.52E-10
U-235	15117-96-1	3.00E-03	1.57E-10	6.96E-11	9.44E-11	1.01E-08	5.18E-07
U-235+D	15117-96-1(+D)	3.00E-03	1.63E-10	7.18E-11	9.76E-11	1.01E-08	5.43E-07
U-238	7440-61-1	3.00E-03	1.43E-10	6.4E-11	8.66E-11	9.32E-09	4.99E-11
U-238+D	7440-61-1(+D)	3.00E-03	2.1E-10	8.71E-11	1.21E-10	9.35E-09	1.14E-07

Note: Values are derived from HEAST for Radionuclides (EPA 2001a).

Conversely, if chronic daily intakes exceed this threshold level, there is a potential that some adverse noncarcinogenic health effects might be observed in exposed individuals.

Tables 5.2 and 5.3 list the current values used for calculation of PRGs. These tables will be updated as necessary for the CRA.

5.3 Dermal Exposure to Chemicals

Because intake from dermal contact is estimated as an absorbed dose, EPA recommends using oral toxicity factors, adjusted if possible by a gastrointestinal absorption fraction, to evaluate toxic effects from dermal contact with potentially contaminated media (EPA 1989, 1992c, 2001b). The oral toxicity factor relates the toxic response to an administered intake dose of contaminant, which may be only partially absorbed by the body. When specific gastrointestinal absorption rates are not available, gastrointestinal absorption is assumed to be 100 percent and the unadjusted oral toxicity factor is used to assess the response to dermal absorption. Adjustments will be made to the oral toxicity factors in Tables 5.2 and 5.3 for assessing dermal exposures in the CRA. The values for the adjusted factors and the rationale will be presented in the CRA.

5.4 Identification of Radionuclide Dose Conversion Factors

Dose coefficients will be delineated according to federal guidance (EPA 1988, 1993). Dose coefficients will be tabulated for the committed effective dose equivalent to tissues of the body per unit activity of inhaled or ingested radionuclides. The guidelines were derived to be consistent with current federal radiation protection guidance. The guidelines are intended to serve as the basis for setting upper bounds on the inhalation and ingestion of, and submersion in, radioactive materials in the workplace. The guidance also includes tables of exposure-to-dose conversion factors for general use in assessing average individual committed doses in any population adequately characterized by "Reference Man" (ICRP 1975).

The dose coefficients for external exposure to radionuclides distributed in air, water, and soil will be tabulated in accordance with Federal Guidance Reports Nos. 11 and 12 (EPA 1988, 1993). The dose coefficients are based on dosimetric methodologies and include the results of calculations of the energy and angular distributions of the radiations incident upon the body and transport of these radiations within the body. Particular effort was devoted to expanding the information available for the assessment of the radiation dose from radionuclides distributed on or below the ground surface.

Dose coefficients for external exposure relate the doses to organs and tissues to the concentrations of radionuclides in environmental media. This is referred to as "external exposure," because the radiations arise outside the body. Intakes of radionuclides may also be by inhalation or ingestion, where the radiations are emitted inside the body. In either case, the dosimetric quantities of interest are the radiation dose received by the more radiosensitive organs and tissues of the body. Radiation of concern for external exposures are those sufficiently penetrating to traverse the overlying tissues of the body and deposit ionizing energy in radiosensitive organs and tissues. Penetrating radiations are limited to photons, including bremsstrahlung, and electrons. The radiation dose depends on the temporal and spatial distributions of the radionuclide to which a human is exposed. The mode considered for the CRA for external exposure is exposure to contamination on or in the ground.

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6.0 HUMAN HEALTH RISK CHARACTERIZATION

Action: Characterize risks for the CRA in two ways:

1. Risk to an onsite WRW will be assessed based on exposure to COCs developed on the basis of the EUs, as discussed in Section 4.2.
2. Risk to an onsite WRV will be assessed based on exposure to COCs developed on the basis of the EUs.

To characterize risks, the chemical-specific intakes calculated in the exposure assessment are multiplied by the applicable chemical-specific, dose-response factors to compute estimates of the cancer risk for an individual over a lifetime of exposure, or the intakes are compared with RfDs (chronic, subchronic, or acute) for noncarcinogenic health effects. The nature, weight-of-evidence, and magnitude of uncertainty for the potential critical health effects are considered. The process of quantifying health risks includes the following:

- Calculating and characterizing carcinogenic effects for each COC, receptor, pathway, and exposure scenario, using both Tier 1 and Tier 2 EPCs;
- Calculating and characterizing noncarcinogenic effects for each COC, receptor, pathway, and exposure scenario, using both Tier 1 and Tier 2 EPCs;
- Calculating and characterizing radiation dose for each radionuclide COC, receptor, pathway, and exposure scenario, using both Tier 1 and Tier 2 EPCs; and
- Conducting qualitative (or quantitative, if necessary) uncertainty analysis.

6.1 Calculating and Characterizing Carcinogenic Effects

The following calculation will be used to determine carcinogenic effects by obtaining numeric estimates (that is, unitless probability) of lifetime cancer risks:

$$Risk = Intake \times CSF \qquad \text{(Equation 6-1)}$$

Where:

Risk = potential lifetime excess cancer risk (unitless probability)

Intake = chronic daily lifetime intake (mg/kg-day or pCi) from equations in Table 4.7

CSF = cancer slope factor ($[\text{mg/kg-day}]^{-1}$ or pCi^{-1})

CSFs will be used as provided in IRIS. Inhalation and oral ingestion CSFs are used with their respective inhalation and ingestion intakes to estimate potential carcinogenic health risks. The CSFs used are presented and discussed in the toxicity assessment (Section 5.1).

Cancer risks are summed separately across all potential chemical carcinogens and radionuclides considered COCs in the risk assessment, using the following equations:

$$Risk_{Tc} = \Sigma Risk_{ic} \qquad \text{(Equation 6-2)}$$

$$Risk_{Tr} = \Sigma Risk_{ir} \qquad \text{(Equation 6-3)}$$

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Where:

$Risk_{Tc}$ = total chemical cancer risk (unitless probability)

$Risk_{ic}$ = risk estimate for the i^{th} chemical contaminant (unitless probability)

$Risk_{Tr}$ = total radionuclide cancer risk (unitless probability)

$Risk_{ir}$ = risk estimate for the i^{th} radionuclide contaminant (unitless probability)

These equations are an approximation of the precise equation for combining risks to account for the probability of the same individual developing cancer as a consequence of exposure to two or more carcinogens. The difference between the precise equation and this approximation is negligible for total cancer risks less than 0.1 (10^{-1}). The risk summation assumes independence of action by the compounds (that is, no synergistic or antagonistic actions). The limitations of this approach include conservative risk estimates due to the use of multiple upper-bound estimates of CSFs; increased uncertainty when adding potential carcinogenic risk across weight-of-evidence cancer classes (A through C); and uncertainty due to possible interactions among carcinogens.

A table of risks for each exposure scenario will be presented to show contaminant- and pathway-specific risk, with contaminants presented by rows and pathways presented by columns. Risks will be subtotaled across pathways for each contaminant.

A total carcinogenic risk will also be summed separately for chemicals and radionuclides across weight-of-evidence classifications as an aid in the discussion of the uncertainty of the estimates. In accordance with EPA guidance, only one significant digit is retained when summarizing calculated risks (EPA 1989).

The CRA is an assessment of the human health and ecological risks from residual contamination. The pathways and contaminants driving the risk will be noted and accompanied by a discussion of any qualifying information.

In addition to presenting the incremental cancer risks due to contaminants at the Site, perspective may be provided by giving examples of typical background sources of risk, such as for arsenic or uranium. The text will note assumptions associated with the calculations, and discuss the importance of background risks associated with each exposure scenario. The CRA summary section will present risks for each scenario.

6.2 Calculating and Characterizing Noncarcinogenic Effects

Health risks associated with exposure to individual noncarcinogenic compounds are determined by calculating HQs and HIs. The noncarcinogenic HQ is the ratio of the intake or exposure level to the RfD, as follows:

$$HQ_i = Intake_i/RfD_i \quad \text{(Equation 6-4)}$$

Where:

HQ_i = noncarcinogenic HQ for i^{th} substance

$Intake_i$ = intake for i^{th} substance (mg/kg-day) for appropriate exposure period

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RfD_i = reference dose for ith substance (mg/kg-day) for appropriate exposure duration

Inhalation and oral ingestion RfDs are used with their respective inhalation and ingestion intakes to estimate potential noncarcinogenic health effects. Intake and RfD are expressed in the same units and represent the same exposure period. The RfDs used are presented and discussed in the toxicity assessment of the CRA. COCs that have been determined to have subchronic (two-week to seven-year exposure) or acute (less than two-week exposure) effects in the toxicity assessment will be characterized using subchronic or acute RfDs, or other dose-response information, as available.

HIs are the summed HQs for each chemical across an exposure pathway. An HI is calculated using the following equation:

$$HI_{pw} = \sum HQ_i \qquad \text{(Equation 6-5)}$$

Where:

HI_{pw} = HI for an exposure pathway (unitless)

HQ_i = HQ for the ith COC (unitless)

The HI_{pw} values are not statistical probabilities of a potential effect. If the HI_{pw} exceeds one, there is a concern for potential noncarcinogenic health effects. In general, the greater the HI above one, the greater the level of concern. However, the level of concern does not increase linearly as the HI approaches or exceeds one.

Noncarcinogenic effects will be presented in the CRA tables similar to those used in the presentation of carcinogenic risk. Each table will show contaminant- and pathway-specific effects with contaminants presented in rows, and pathways presented by columns. HI_{pw}s will be subtotaled across pathways to develop an HI for the exposure scenario (HI_{es}), if the same individuals would consistently be exposed to more than one pathway for each contaminant.

HQ_is approaching or exceeding one will be segregated and summed by mode of action or target organ to calculate the total HI by target organ (HI_{to}). A total HI_{to} will also be summed across all pathways and contaminants for a specific receptor scenario. Both of these procedures are subject to limitations. One significant digit is retained when summarizing the calculated indices.

The CRA will evaluate HQs and HIs that exceed one. Factors such as uncertainty inherent in the RfD(s), mode(s) of action, target organ(s), and severity of health effect(s) will be discussed. The pathways and contaminants driving the risk will be noted and discussed. A summary table presenting HI_{es} subtotals for all scenarios will be created for presentation in the CRA risk summary section. This may be presented by placing the results for each scenario in rows, and providing information on HIs, dominant COCs, and dominant pathways in columns.

6.3 Calculating and Characterizing the Dermal Exposure Effects

As discussed in the toxicity assessment (Section 5.0), evaluation and assessment of risks for the dermal route are based on absorbed dose as opposed to the administered dose for other

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routes. The dermally absorbed dose (DAD) must be calculated separately and the toxicity factors adjusted according to estimated gastrointestinal absorption in critical studies. The cancer risk or HI is calculated using Equation 6-6:

$$Dermal\ cancer\ risk = DAD \times SFabs \qquad \text{(Equation 6-6)}$$

Where:

DAD	=	dermally absorbed dose (mg/kg-day)
SFabs	=	absorbed CSF $(mg/kg\text{-}day)^{-1}$

The noncarcinogenic health hazard is calculated in a similar way:

$$Dermal\ cancer\ risk = DAD\ /\ RfDabs \qquad \text{(Equation 6-7)}$$

Where:

DAD	=	dermally absorbed dose (mg/kg-day)
RfDabs	=	absorbed RfD (mg/kg-day)

6.4 Calculating and Characterizing Radiation Dose

Radiation dose will be calculated per EPA guidance in Risk Assessment Guidance for Superfund (RAGS), Part A, Chapter 10 (EPA 1989). The following calculation will be used to determine the radiation dose (NCRP 1985):

$$Dose = DCF \times Intake \qquad \text{(Equation 6-8)}$$

Where:

DCF	=	dose conversion factor (millirems per picocurie [mrem/pCi] or millirems per picocurie per gram [mrem/pCi/g])
Intake	=	radionuclide intake or media concentration (pCi or pCi/g)

Inhalation and oral ingestion DCFs are used with their respective inhalation and ingestion intakes to estimate radiation dose. For external irradiation, external DCFs are used with their respective soil concentrations to estimate radiation dose. DCFs are calculated using mathematical extrapolation models based on human epidemiological studies.

Radiation dose is summed separately across all potential radionuclides considered in the dose assessment using the following equation:

$$Dose_T = \Sigma Dose_i \qquad \text{(Equation 6-9)}$$

Where:

$Dose_T$	=	total radiation dose (millirems [mrem])
$Dose_i$	=	radiation dose estimate for the i^{th} radionuclide (mrem)

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A table of radiation doses for each exposure scenario will be created to show contaminant- and pathway-specific dose, with radionuclides presented by rows and pathways presented by columns. Reasonable exposure pathway combinations will be identified and the likelihood that the same individuals would consistently be exposed by more than one pathway will be evaluated. In most situations, a receptor could be exposed by several pathways in combination. For these situations, doses will be subtotaled across pathways for each radionuclide.

In addition to presenting the incremental radiation dose due to radionuclides at the Site, perspective may be provided by giving examples of typical background sources of dose from anthropogenic and terrestrial sources. Assumptions associated with the calculations will be noted and discussed. The CRA summary section will present doses for each exposure scenario as well as a brief discussion of the uncertainty of the risk estimates.

6.5 Conducting an Uncertainty Analysis

The uncertainty analysis characterizes the various sources and their contributions to uncertainty in the CRA. These uncertainties are driven by uncertainty in the Site investigation data, likelihood of hypothetical exposure scenarios, transport modes used to estimate concentrations at receptor locations, receptor intake parameters, and toxicity values used to characterize risk. Additionally, uncertainties are introduced in the risk assessment when exposures to several substances across multiple pathways are summed.

The concept of uncertainty can be more fully defined by distinguishing between variability and knowledge uncertainty. Variable parameters are those that reflect heterogeneity in a well-characterized population, for which the distributions would not generally be narrowed through further measurement or study. Certain parameters reflect a lack of information about properties that are invariant and whose single, true value could be known exactly by the use of a perfect measuring device. Where appropriate, qualitative uncertainty analysis may distinguish between variability and uncertainty. This type of uncertainty analysis will identify each key source of uncertainty, present an estimate of the relative impact of the uncertainty on the CRA, and include any clarifying remarks.

There are four stages of analysis applied in the risk assessment process that can introduce uncertainties:

- Data collection and evaluation;
- Exposure assessment;
- Toxicity assessment; and
- Risk characterization.

The discussion of uncertainty is an important component of the risk assessment process. Point estimates of risk do not fully convey the range of information considered and used in developing the assessment (EPA 1992c). To provide information about the uncertainties associated with the reasonable maximum exposure (RME) estimate, uncertainties identified during the CRA process will be discussed qualitatively. In some cases, the effects on risks of the variability in some factors may be calculated to show potential risk ranges.

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7.0 ECOLOGICAL RISK ASSESSMENT

Scope: Develop and document the methodology for the ERA portion of the CRA.

This section provides the methodology for the ERA in support of the CRA. The methodology utilizes existing RFETS risk assessment methodologies (DOE 1996b, 1996c) and more recent EPA guidance on performing ERAs at Superfund sites (EPA 1997, 1999, 2000a, 2001c).

Previous ERA efforts at RFETS include an ERA for the Woman and Walnut Creek watersheds in the BZ that was conducted in 1996, the results presented in the Draft Final Phase I RFI/RI Report Appendix N, Woman Creek Priority Drainage Operable Unit No. 5 (DOE 1995b). Hereafter, this ERA will be referred to as the Draft Watershed ERA. The Draft Watershed ERA has not been approved or formally accepted by the regulatory agencies, and was based on available data collected through 1995. However, available analytical and biological data from the Draft Watershed ERA will be used, if appropriate, to augment the updated and current comprehensive ERA effort.

An ERA has not been performed for areas within the IA. Historically the IA did not represent a significant ecological resource. Buildings, parking lots, or other developed areas formerly covered much of the IA and, as a result, the IA did not represent a significant ecological resource. However, all buildings, structures, and parking lots are currently being dismantled and removed. The reasonably anticipated future land use for the IA will be part of a U.S. National Wildlife Refuge, and an ERA is needed to characterize the potential exposure and ecological risk due to residual contamination in soil or other media.

An overview of the ERA portion of the CRA is shown on Figure 7.1. The CRA is intended to document residual ecological risks following the ongoing accelerated actions at the Site. The analysis will include two main phases. Data on ecological contaminants of interest (ECOIs) in abiotic media from the Site will be compared to conservative ESLs that have been developed for abiotic media and a range of ecological receptor types (Appendix B). The analysis will be conducted using all Site data from previous investigations and confirmation sampling from accelerated actions or additional data collection not related to accelerated actions. The ESL comparisons will be used to identify ecological contaminants of potential concern (ECOPCs) for each receptor of concern (ROC) and EU and to map the locations where the ESLs are exceeded. The ecological analysis will be conducted for the same EUs as defined for the HHRA.

A thorough characterization of risk will be conducted for the ECOPCs identified in the comparison to the ESLs. The risk characterization will utilize additional lines of evidence as outlined on Figure 7.1 and will be completed in consultation with the regulatory agencies. Data gaps will be addressed prior to the CRA in a DAR intended to identify areas where additional data are needed to support the CRA.

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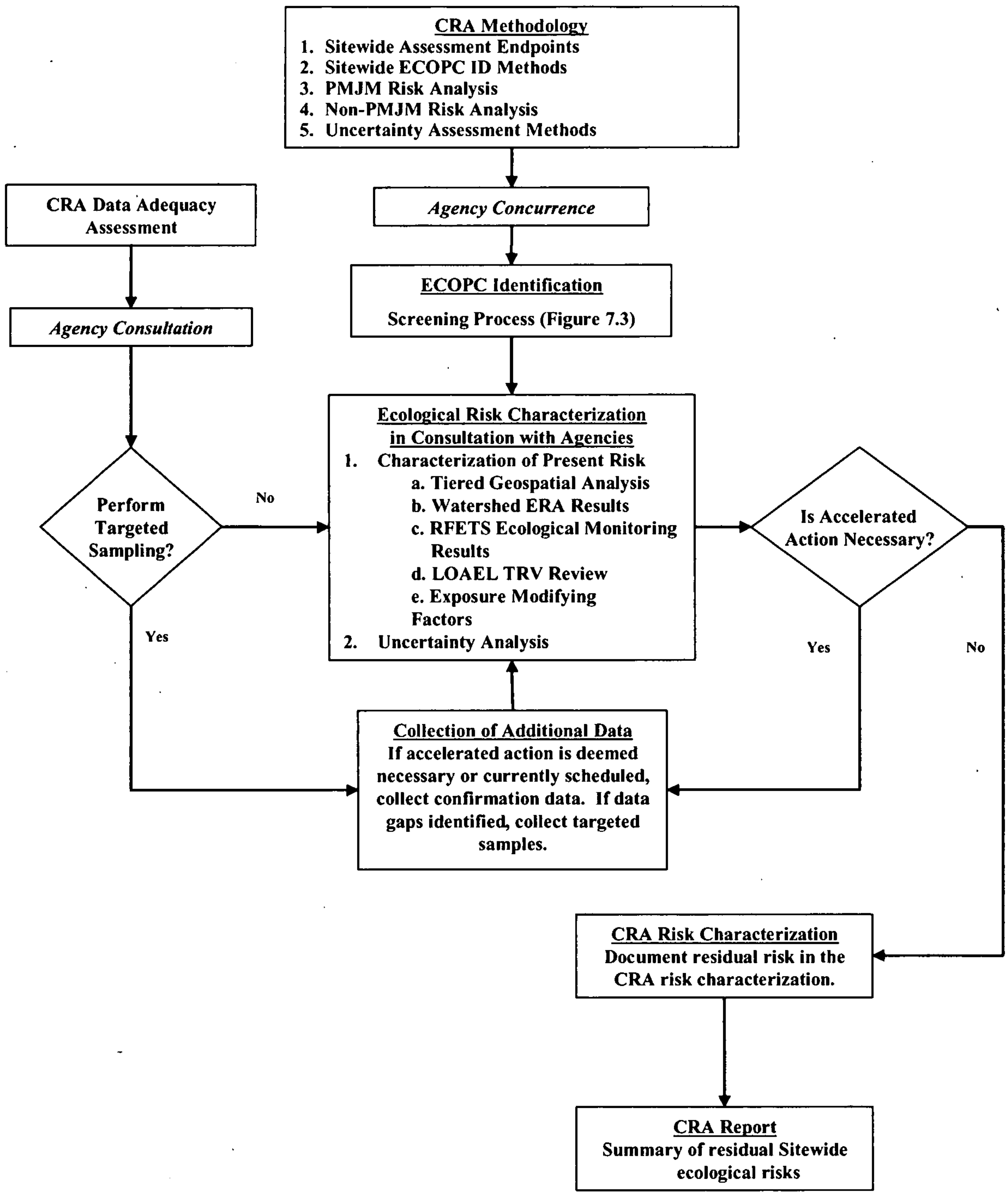
Figure 7.1 Sequence of Activities for the ERA



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ESLs will be specific to the ROCs and the level of protectiveness required. For vertebrate ROCs that are not considered to be of special status (rare or threatened) and, therefore, are afforded additional protection by state or federal statute (for example, threatened or endangered species), ESLs will represent exposures equal to the threshold ESL (tESL), when available. tESLs are based on the geometric mean between no observed adverse effect levels (NOAELs) and lowest observed adverse effect levels (LOAELs) from chronic sublethal endpoints. ESLs for the Preble's meadow jumping mouse (PMJM) will be more protective because it is a rare species with legal protection over and above the typical receptor. ESLs must be adequately conservative to provide screening-level protection on a subpopulation level. PMJM ESLs will be based on NOAELs. ESLs are being developed for the analytes included in RFCA Attachment 5, Table 3 (DOE et al. 1996 [as modified]) and other analytes, as necessary.

Data used for the ESL comparison process will be from abiotic media (surface and subsurface soil, surface water, and sediments). For areas that may have undergone accelerated actions, data will be from a combination of confirmation sampling and historical sampling in areas where no removals have occurred. Additional data may also be collected pending the results of the DAR. In addition, the ERA may use the results of Sitewide surface water and groundwater transport modeling efforts to predict exposure of aquatic and terrestrial species at points of potential discharge, such as hillside seeps (terrestrial) and streams (terrestrial and aquatic).

7.1 Use of Draft Watershed Ecological Risk Assessment in the Comprehensive Risk Assessment

Purpose: The results of the previously completed Draft Watershed ERA will be used to support the current assessment of ecological risks from residual contamination at the Site.

Conclusions and data from the Draft Watershed ERA will be important lines of evidence in the risk characterization process. The Draft Watershed ERA represents a comprehensive exposure and risk assessment conducted specifically for the RFI/RI process at RFETS. The results will be used on several levels. For example, ESL calculations include assumptions about the extent to which ECOPCs are accumulated from abiotic media to biota in the food chain. The literature-based bioaccumulation factors (BAFs) used in developing the ESLs are typically conservative and tend to overestimate the ECOPC concentrations in forage and prey, which, in turn, tend to overestimate risk. BAFs are site-specific and the assumptions used in the ESL calculations may not match the reality at the Site. The Draft Watershed ERA contains data on ECOPC concentrations in biota throughout the active areas of the Site. These data were used in exposure and risk calculations, eliminating the need for the use of BAFs because the actual ECOPC concentrations in tissue were available for the exposure calculations. Therefore, results of the exposure analyses from the Draft Watershed ERA will be thoroughly reviewed for their applicability to the CRA and, where appropriate, biotic data

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will be used in the CRA exposure analysis portion of the risk characterization to make the analysis more Site-specific than would be possible with only generic BAFs.

Data from the Draft Watershed ERA, RFI/RI reports, or ecological monitoring studies may also be used in the DAR to help determine whether additional data are needed to assess risks in specific areas. This may be especially applicable to PMJM habitats along the creeks where soil and biota data were collected. The results of the Draft Watershed ERA may be used to determine whether additional data are needed to fill spatial data gaps along the drainages. Results of ecological monitoring at the Site may be used to help determine whether there is properly functioning habitat in the EUs.

7.2 Comprehensive Risk Assessment Background, Site Conceptual Model, and Data Quality Objectives

> **Actions:** Specify information needed on the physical setting; develop an SCM of ecological receptors and exposure pathways to guide the ERA process; specify risk management goals and assessment endpoints; and develop DQOs to guide the ERA process.

7.2.1 Environmental Setting

The description of the environmental setting at RFETS will be presented in Section 2.0 of the RI/FS Report and will include the physical characteristics of the Site, such as topography, geology, and hydrology. The types and extent of plant and animal communities present on Site will be discussed in the ERA.

After accelerated actions, species diversity, abundance, and habitats may change significantly. Therefore, it will be important to determine the following:

- Present and future extent of wetlands habitat on Site;
- Sensitive/protected plant species habitat (for example, Ute Ladies'-Tresses) on Site;
- Present and future PMJM habitat locations on Site;
- Other protected or special status species sightings or habitats on Site (for example, bald eagles and peregrine falcons); and
- Vegetation/habitat types to be introduced in the IA.

Much of the above information is available from ecological characterization and monitoring activities for the Site. Site physical characteristics are well described. Surface water and groundwater flow patterns and future Site configuration have been discussed in various reports that address the Sitewide water balance, actinide migration, and land configuration. Results of these studies will be used in conjunction with data on nature and extent of contamination, select assessment endpoints, and ECOPC screening methodologies to complete the problem formulation phase of the ERA. Where data from other studies, such as the Draft Watershed ERA, are used to make decisions, the specific data on which a

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conclusion or result will be presented or the location of the original document where the data can be found will be cited.

7.2.2 Site Conceptual Model

Development of the SCM is the first step in the problem formulation, or planning, phase of ERAs (EPA 1997). The purpose of the SCM is to help identify environmental stressors and the potential pathways by which ecological receptors may be exposed to them. This step allows investigators to identify the potentially complete pathways that will become the focus of the ERA.

An SCM for the Draft Watershed ERA was described in the Sitewide Conceptual Model Technical Memorandum (SCMTM) (DOE 1996c). The SCMTM established the relationships among the key components of the RFETS ecosystem and included the following information:

- Description of the environmental setting at RFETS, including the natural physical and biological systems and a brief description of the primary contaminant-source areas or IHSSs;
- Description of the important contaminant fate and transport pathways in abiotic media;
- Description of the important exposure pathways, including primary exposure media, exposure points, receptor guilds, and exposure routes;
- Description of receptor guilds and identification of key species in each guild to be used in representative exposure estimates at RFETS;
- Species-specific exposure parameters to be used in estimating exposure to key receptors;
- Measurement endpoints for which data have been collected;
- A summary of existing environmental data, data sources, and ongoing monitoring programs; and
- A description of data gaps associated with determination of the nature and extent of potential contamination.

The SCM has been updated to reflect the most appropriate ecological receptors for the Site as a wildlife refuge (Figure 7.2). The purpose of the SCM is to help identify potential pathways by which ecological receptors may be exposed to ECOPCs. The identified pathways become the focus of the ERA. The SCM will also be used to identify measurement endpoints for use in evaluation of assessment endpoints (Suter 1993).

Figure 7.2 identifies several potential pathways that describe how a receptor might contact a ECOPC. The figure identifies pathways that are probably complete and potentially significant pathways for exposure of the receptor groups. Some of the pathways (inhalation and dermal contact with surface water for terrestrial fauna) are designated as potentially complete but insignificant and will not be quantitatively evaluated. Inhalation of ECOPCs in ambient (surface) air is generally thought to be insignificant compared to ingestion pathways (EPA 2000c) and is generally not evaluated quantitatively in ERAs. In addition, there is little information available to assess the potential toxicity of ECOPC concentrations in air. Therefore, while the pathway may not be significant, it is identified as a source of uncertainty

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that may result in an underestimate of exposure. Dermal exposure to surface water is also thought to be a minor pathway for most terrestrial species at RFETS. For metals, polar organic compounds, and radionuclides, skin, fur, and feathers are generally a significant barrier to absorption. Nonpolar organic ECOPCs are more likely to be transferred across external surfaces. However, the low concentrations at which such compounds are found in surface water and the low absorption rates for most terrestrial receptors limit the potential exposures. For terrestrial vertebrates at RFETS, oral ingestion is likely to be more significant and "drive" risk rather than either inhalation or dermal contact. For some scenarios, such as burrowing animals, dermal pathways may be evaluated for organic ECOPCs in soil. However, the oral pathway is expected to be the most important exposure pathway for ECOPCs.

Specifically, the ERA will provide the following:

- Description of the important contaminant fate and transport pathways in abiotic and biotic media;
- Description of the important exposure pathways, including primary exposure media, exposure points, receptor guilds, and exposure routes;
- Description of receptor guilds and identification of key species in each guild to be used in conservative and representative exposure estimates at RFETS;
- Species-specific exposure parameters to be used in estimating exposure to key receptors; and
- Measurement endpoints for which data have been collected.

7.2.3 Ecological Risk Management Goals and Endpoints

In order to focus ERAs, EPA (1997) recommends identifying overall site management goals, assessment, and measurement endpoints on which the analysis of risk should focus. Assessment endpoints are the explicit description of the ecological values to be protected as a result of management actions at a site. Measurement endpoints are specific data collected to address the assessment endpoints in an attempt to answer the risk questions as they relate to the risk management goals at the site. The overall risk management goal identified for use in developing the ERA for the CRA is:

"Site conditions due to residual contamination should not represent significant risk of adverse ecological effects to receptors from exposure to Site-related residual contamination."

Significant adverse ecological effects imply toxicity that results in reductions in survivorship or reproductive capability that threaten populations or communities at RFETS. For species that are afforded additional regulatory protection due to their rare or threatened status, such as PMJM, significant adverse effects can occur even if individuals are affected. Therefore, the assessment for PMJM will address the potential for individual mice to be adversely affected by contact with ECOPCs. For other species with stable or healthy populations, the assessment will focus on population-level effects where some individuals may suffer adverse effects, but the effects are not ecologically meaningful because the overall Site population is not significantly affected.

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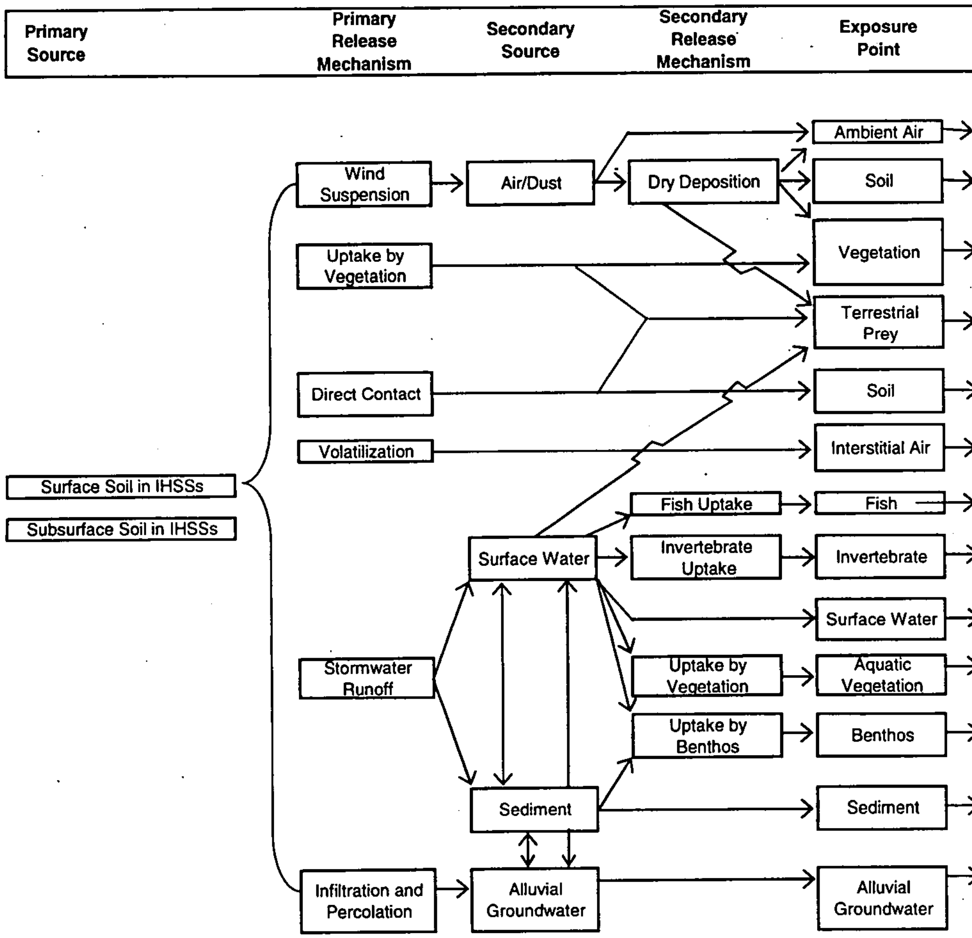
Figure 7.2 Ecological Site Conceptual Model



Exposure Point	Exposure Route	Vegetation	Terrestrial Fauna: Herbivore	Terrestrial Fauna: Predator	Aquatic Fauna: Herbivore	Aquatic Fauna: Predator
Ambient Air	Inhalation		X (1)	X (1)		
Soil	Ingestion		X	X		
Soil	Direct Contact	X	X	X		
Vegetation	Ingestion		X			
Terrestrial Prey	Ingestion			X		
Soil	Ingestion		X	X		
Soil	Direct Contact	X	X	X		
Interstitial Air	Inhalation		X (2)	X (2)		
Fish	Ingestion			X		X
Invertebrate	Ingestion			X		X
Surface Water	Ingestion		X	X		X(1)
Surface Water	Direct Contact	X	X(1)	X(1)		X
Aquatic Vegetation	Ingestion		X		X	
Benthos	Ingestion			X		X
Sediment	Ingestion		X	X	X	X
Sediment	Direct Contact	X	X(1)	X(1)	X	X
Alluvial Groundwater	Direct Contact	X				

Receptor Guilds

Pathway Evaluation

X	Potentially Significant, Evaluated
X(1)	Complete, but Insignificant, Not Evaluated
X(2)	For Burrowing Animals Only, Evaluated on a Case-By-Case Basis
	Incomplete Pathway, Not Evaluated

For PMJM, the overall risk management goal and endpoints are:

- **Goal**: Prevent adverse effects on individual PMJM due to lethal, mutagenic, reproductive, systemic, or general toxic effects of contact with ECOPCs from the Site.
- **Assessment Endpoints**: Survival, growth, and reproduction of individual PMJM at the Site.
- **Measurement Endpoints**: Comparison of total intake measures, calculated from PMJM-specific ingestion models, of ECOPCs from abiotic data (soil, sediments, and surface water) and food items to toxicity reference values (TRVs).

For non-PMJM receptors, the risk management goal and endpoints are:

- **Goal**: Prevent adverse effects on populations due to lethal, mutagenic, reproductive, systemic, or general toxic effects of contact with ECOPCs from the Site.
- **Assessment Endpoints**: Survival, growth, and reproduction adequate to sustain populations at the Site.
- **Measurement Endpoints**: Comparison of total intake measures, calculated from receptor-specific ingestion models, of ECOPCs from abiotic data (soil, sediments, and surface water) and food items to TRVs.

The receptors to be included as assessment endpoints for the Site are shown in Table 7.1. These receptors were identified based on ecological functional groups, then representative species were identified to focus the analysis.

Table 7.1 Representative Species for the ERA

Functional Group	Representative Species
Burrowing Small Mammal	Black-tailed Prairie Dog
Herbivorous or Omnivorous Small Mammal	Deer Mouse
Insectivorous Small Mammal	Deer Mouse
Herbivorous or Omnivorous Bird	Mourning Dove
Ruminant Wildlife	Mule Deer
Mammalian Predator	Coyote
Avian Predator	American Kestrel
Plant	General
Terrestrial Invertebrate	General
Aquatic Life	General aquatic life, including amphibians and benthic macroinvertebrates (sediment exposure)

7.2.4 Data Quality Objectives

As with the HHRA process, the approach to the ERA is presented in the format of DQOs (EPA 1997).

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Step 1: State the Problem

Potentially toxic substances have been released at the Site. Ecological receptors could be exposed to the substances. To date, ecotoxicological risks have been characterized only for portions of the BZ in the Woman Creek and Walnut Creek watersheds (DOE 1995b).

The problem to be addressed by the ERA is:

> *"The risks to all reasonably expected ecological exposures to residual contaminants present in the environmental media following accelerated actions must be quantified in a technically sound and defensible manner."*

Step 2: Identify the Decision

The ERA will characterize what is known about the exposures, and whether they have resulted, or could result, in significant adverse effects to ecological receptors. The overall Site management question to be addressed by the ERA is:

> *"Are residual long-term ecological risks from Site-specific contaminants acceptable for the long-term Site use and management goals?"*

In order to address this general decision, additional decisions to be addressed include:

- Has a methodology been developed to adequately assess ecological risks?
- Has a methodology been developed to adequately identify ECOPCs?
- Is the CRA SCM adequate to define all viable exposure scenarios, exposure pathways, and receptors based on the reasonably anticipated future land use?
- Have all EUs been adequately defined and established?
- Have the nature and extent of inorganic, organic, and radionuclide analytes within EUs been identified with adequate confidence, based on evaluation of Site process knowledge and analytical data?
- Have samples of adequate number and quality been collected within EUs to perform the risk assessment?

Step 3: Identify the Inputs to the Decision

Information needed to resolve the ERA decision statements is as follows:

- Existing data for areas under consideration;
- Results from a DQA screen (Section 3.1.5) applied for each type of environmental medium as prescribed in this Methodology;
- Results from the ECOPC screen compared to ecotoxicologically based screening level values;
- Maps for ECOPCs depicting the distribution of sampling locations with concentrations compared to ESLs;

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- Ecological data that have become available since the completion of the previous ERAs (for example, the Integrated Ecological Monitoring program); and
- Data and results from the previous ERAs conducted at RFETS.

Step 4: Define the Study Boundaries

Study boundaries are used to determine the areas from where data will be used, and identify where future sampling will occur. These study boundaries are as follows:

- All available, qualified data will be used. The assessment will be confined to the area within the current RFETS boundary unless the on-site assessment indicates circumstances that could alter the conclusions of the off-site assessment performed earlier for OU 3 (DOE 1996a).
- Soil will be assessed generally from the land surface to a depth below ground surface that is consistent with both potential contamination and the depth to which mammals may burrow in the RFETS environment (8 feet).
- The ERA portion of the CRA will consider ECOPCs in surface water, sediment, and soil. The results of modeling the transport of groundwater to surface water will be compared to ESLs (that is, State of Colorado water quality standards) for aquatic life. Further assessment will be performed for ECOPCs failing the screening-level assessment.

Step 5: Develop a Decision Rule

In addition to the decision rules cited for data adequacy in Section 3.0, decision rules that describe how the data will be evaluated for the ERA are listed below.

- The ECOPCs that pass through the screening process shown graphically on Figure 7.3 will be evaluated in the risk characterization phase of the CRA.

<u>Non-PMJM Receptors</u>

- For large home range receptors (mule deer and coyote), if the Sitewide and EU-specific 95UCL of the mean does not exceed the NOAEL ESL or tESL, no further risk assessment is necessary for that exposure scenario and the results will be documented in the CRA.
- For small home range receptors (including terrestrial plants and invertebrates), if the EU-specific 95UCL of the 90th percentile of the distribution of data does not exceed the NOAEL ESL or tESL, no further risk assessment is necessary and the results will be documented in the CRA Report.
- For nonvertebrate terrestrial receptors, sediment and surface water ECOIs that have concentrations not exceeding the appropriate chronic or threshold level ESL will not require further assessment and will be documented in the CRA Report,
- All receptor/ECOPC pairs that do not meet the decision rules discussed above will be carried into a risk characterization in consultation with the regulatory agencies. The risk characterization process will be documented in the CRA and will include:

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- Tiered geospatial analysis;
- Discussion of alternative TRVs;
- Review of ECOPC bioavailability;
- Evaluation of Site-specific tissue data;
- Review of previous risk assessment data;
- Evaluation of potential Type II errors;
- Spatial variability of ECOPC concentrations; and
- Other pertinent techniques to further characterize risk.

PMJM Receptors

- Risks from ECOPCs to the PMJM receptor, within the designated PMJM habitat, will be evaluated on a location-by-location basis. Samples where the most conservative ESL is exceeded by the sample concentration will be mapped.
- Those ECOPCs that do not meet the decision rules discussed above will be carried into a risk characterization process in consultation with the regulatory agencies in order to further characterize potential risk to the PMJM receptor. This process will be documented in the CRA and may include:
    - Geospatial analysis of data;
    - Review of toxicity, bioavailability, and other potential exposure-modifying factors;
    - Review of previous risk assessment data;
    - Evaluation of potential Type II errors; and
    - Other pertinent techniques to further characterize risk.

Step 6: Specify Tolerable Limits on Decision Errors

Several sources potentially contribute uncertainty to the CRA. Best professional judgment and input from the consultative process will be used for decisions regarding data gaps and risk management actions. The rationale and justification will be included in the CRA Report.

For exposure areas that are evaluated based on the 95UCL of the mean, the Type I error rate is fixed at 5 percent regardless of data quality. For this evaluation, the probability of a Type II decision error, which depends strongly on data quality, will remain undefined unless it is deemed necessary to define it in order to adequately characterize risk in the CRA.

For exposure areas that are evaluated based on the 95UCL of the 90^{th} percentile of the distribution of soil concentration values, the Type I error rate should not be more than 5 percent when the true 90^{th} percentile is larger than the ESL. The Type II error rate will remain undefined unless it is deemed necessary to define it in order to provide adequate data to characterize risk in the CRA.

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Step 7: Optimize the Design

Based on the iterative nature of the DQO process, any decision that is not consistent with project goals will result in a reinitiation of the DQO process. If determination of the nature and extent of analytes is found to be inadequate, further sampling will be initiated. If sampling power is determined to be inadequate for any given scenario and set of analyte data, more samples may be collected and the sampling power can be recalculated.

7.2.5 Data Types and Adequacy

The SCM suggests that ecological receptors may be exposed to ECOPCs in abiotic and biological media. Site data on ECOPC concentrations in soil, surface water, and sediments will be evaluated to support the CRA. Biological tissue analysis results will not be used in the initial phase of the CRA assessments. However, biological tissue analysis to describe potential uptake of ECOPCs into prey and forage species will be considered in the risk characterization phase.

The Draft IABZSAP (DOE 2004a) identifies laboratory analytical methods to provide data with adequately low method detection limits (MDLs) and practical quantitation limits (PQLs) to allow meaningful comparison to ecological screening levels in abiotic media. A table presenting these values will be provided in the CRA to indicate where detection limits are adequate for use.

ECOPC concentrations in soil and sediment will be expressed as "total recoverable." ECOPC concentrations in surface water will be appropriately compared to water quality standards for protection of aquatic life. Surface water data used to assess risks to wildlife drinking the surface water will be based on total recoverable (that is, unfiltered) analyses. Data on ECOPC concentrations in biological tissue were collected for the Draft Watershed ERA and associated studies. These data may also be used in a line-of-evidence approach to risk characterization after the ECOPC identification steps have been completed. Data V&V will be conducted as for the HHRA process described in Section 3.1.

In addition to the comparison of ESLs directly to analytical data in the ECOPC identification step, models may be used to estimate ECOPC concentrations in stormwater runoff from potentially contaminated soil and groundwater that may surface at seeps or in streams. Both sources of water could contact aquatic biota or wildlife.

Adhering to the specifications of the DQOs as outlined above will ensure the adequacy of data for use in the ERA. In addition, the DQA will help ensure that the quality of data is consistent with RFETS standards.

7.2.6 Ecological Screening Levels

As noted previously, identification of ECOPCs to be evaluated in detail in the risk characterization portion of the CRA will be based on a comparison of Site abiotic media concentrations to ESLs. ESLs for wildlife were developed based primarily on potential ingestion of ECOIs in abiotic media, forage, and prey, and the transfer of ECOIs among these exposure points. The specific methodology for developing ESLs is presented in Appendix B. The following is an overview of the ESL calculation process for each of the environmental media.

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Soil

EPA's ecological soil screening levels (Eco-SSLs) (EPA 2003b) process was used as general guidance for developing soil ESLs or soil screening levels (SSLs). The Eco-SSL process outlines the acquisition of primary literature sources, followed by extensive review and scoring of documents.

As an alternative to this lengthy and time-consuming process, available compilations of TRVs from several sources were used extensively to obtain reliable and defensible values. In order of preference, these sources include:

- Ecological Soil Screening Level Guidance (EPA 2003b);
- U.S. Navy Soil Screening Levels (PRC 1998); and
- Oak Ridge National Laboratories (ORNL) (Sample et al. 1996).

For a subset of ECOIs and for those ECOIs without previously published TRVs, a literature review was conducted to obtain relevant toxicity information. Only studies using chronic (or subchronic) exposure periods and measuring growth, development, reproductive, and mortality endpoints were selected for use in the calculation of ESLs. The data scoring and weighting system described in the Eco-SSL guidance (EPA 2003b) was used to score the data and calculate the necessary TRVs for those ECOIs that underwent a literature review resulting in more than one applicable TRV.

ECOIs with no or inadequate toxicity data available were identified and handled on a case-by-case basis with input from the regulatory agencies.

No interclass extrapolations were used to extrapolate avian TRVs from mammalian endpoints. In addition, for those ECOIs that have only a LOAEL TRV available, the NOAEL TRVs were estimated by dividing by 10. No estimates of LOAEL TRVs were made.

For those ECOIs that have adequate TRV data available (that is, no estimation of a NOAEL or LOAEL), a tESL was also calculated by estimating the geometric mean between the NOAEL and LOAEL TRVs.

For small receptors with small- to moderate-sized home ranges, average intake parameters, such as the ingestion rate of food, were used in the ESL calculation process. For larger, more wide-ranging receptors (that is, coyote and mule deer), high-end intake exposure parameters were used to provide a conservative estimate of food intake over the entire Site. ESLs for receptors that burrow (for example, prairie dogs) were applied to both surface and subsurface soil. A detailed discussion of the ESL calculation process is presented in Appendix B.

For terrestrial plants and terrestrial invertebrates, benchmark ESLs were derived from several sources (Appendix B). These benchmark values are meant to be compared directly to soil concentrations to provide a general estimate of the potential for risk to the plant and invertebrate receptors.

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Sediments

For sediments, ESLs were developed for many chemicals and are available from several sources. Sediment ESLs are generally expressed as concentration terms and, therefore, require no calculations or assumptions. However, the assumptions underlying the development of sediment ESLs were evaluated to determine consistency with uses at RFETS. A more detailed discussion of the sources used to identify sediment ESLs is provided in Appendix B.

Surface Water

For surface water, ecotoxicologically based water quality criteria (WQC) are available from several sources. For assessment of risk to aquatic receptors, only criteria appropriate for on-site water resources were used. As a screening step, WQC were retrieved from State of Colorado water quality standards, federal Ambient Water Quality Criteria (AWQC), and other databases such as that from ORNL (1999) and the Michigan Department of Environmental Quality (Rule 57, MIDEQ 1996). A more detailed discussion of the sources of WQC is presented in Appendix B.

Radionuclides

Soil benchmarks for radionuclides were developed for RFETS during the Draft Watershed ERA (Higley and Kuperman 1995). Since then, DOE's Biological Dose Assessment Committee (BDAC) has developed additional procedures for assessing exposure and risk to terrestrial and aquatic biota using the Residual Radioactivity Computer Code (RESRAD)-BIOTA (DOE 2002c) computer code for calculating protectiveness that became fully available in December 2003 (DOE 2003c). The RESRAD BIOTA processes were used to verify protectiveness of the Higley and Kuperman benchmarks, and evaluate protectiveness of available surface water and sediment criteria.

Results of the analysis indicated that for some radionuclides, Higley and Kuperman values were higher (less conservative) than those calculated with the RESRAD-BIOTA procedures (Appendix B, Attachment 1). However, it should be noted that for terrestrial animals the radiation exposure limit cited in RESRAD-BIOTA as protective of ecological receptors (1 rad/day) is 10-fold that assumed in Higley and Kuperman (0.1 rad/day). For this analysis, the RESRAD-BIOTA procedures were adjusted to use 0.1 rad/day for comparison to the Higley and Kuperman values. If the default RESRAD-BIOTA values had been used, benchmarks would have been 10-fold higher (that is, less conservative). (Note that the Limits for aquatic animals are the same (0.1 rad/day [Appendix B, Attachment 1])

The analysis also shows that values developed for ecological receptors using either approach were considerably higher than values adopted for managing radionuclide risks to human receptors at the Site. In most cases, soil criteria were two to three orders of magnitude larger. Therefore, if the Site is managed to protect human health and EPCs are calculated using similar methods, then ecological receptors will be protected. This applies to special status species (for example, threatened or endangered) and nonthreatened or endangered receptor groups.

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An exception to the above is exposure to subsurface soils and surface water. For human health assessment in the IA, the pathway to subsurface soil will not be evaluated because institutional controls prevent disturbance of soil; therefore, ESLs will be needed. For surface water, ecological benchmarks are lower than human health values for some radionuclides, primarily due to the higher use rate assumed in the calculations. For these two pathways, RESRAD-BIOTA were used to calculate ESLs that will be used in the CRA.

7.3 Sitewide Ecological Contaminant of Potential Concern Identification Process

Action: Identify ECOPCs for the CRA.

A comprehensive list of Sitewide ECOPCs will be developed for the CRA based on data representing conditions after accelerated actions. ECOIs identified in RFCA Attachment 5, Table 3 (DOE et al. 1996 [as modified]) will form the starting point for the ECOPC identification process shown on Figure 7.3. In addition, the Sitewide database will be screened to identify the maximum detected concentrations of analytes not included in Attachment 5, Table 3. The ECOPC screen will then include maximum concentrations for potentially toxic analytes (that is, analytes that are not nutrients, such as calcium, potassium, and sodium).

The entire Sitewide database will be queried, filtered by media, and subjected to a DQA screen (Section 3.1.5) to identify which data meet the needs of the DQOs discussed in the previous section. Following the DQA screen, two data sets will be created. One will include all Sitewide data; the other will include only sampling locations in PMJM habitat. For each data set, "U-" qualified nondetects will have one-half the reported result concentration substituted. Basic descriptive statistics will then be calculated, such as number of samples, percent detections, maximum detections, mean detection, and standard deviation.

Soil data in each data set will be compared to NOAEL-based ESLs. If the maximum detected concentration of the ECOI does not exceed the NOAEL-based ESL, risks will be considered negligible and the ECOI will be dropped from further analysis in the CRA and the rationale for removing it from further analysis will be recorded and presented in the CRA Report. If the maximum detected ECOI concentration in the PMJM habitat data set exceeds the NOAEL-based ESL, it will be retained as an ECOPC for the PMJM.

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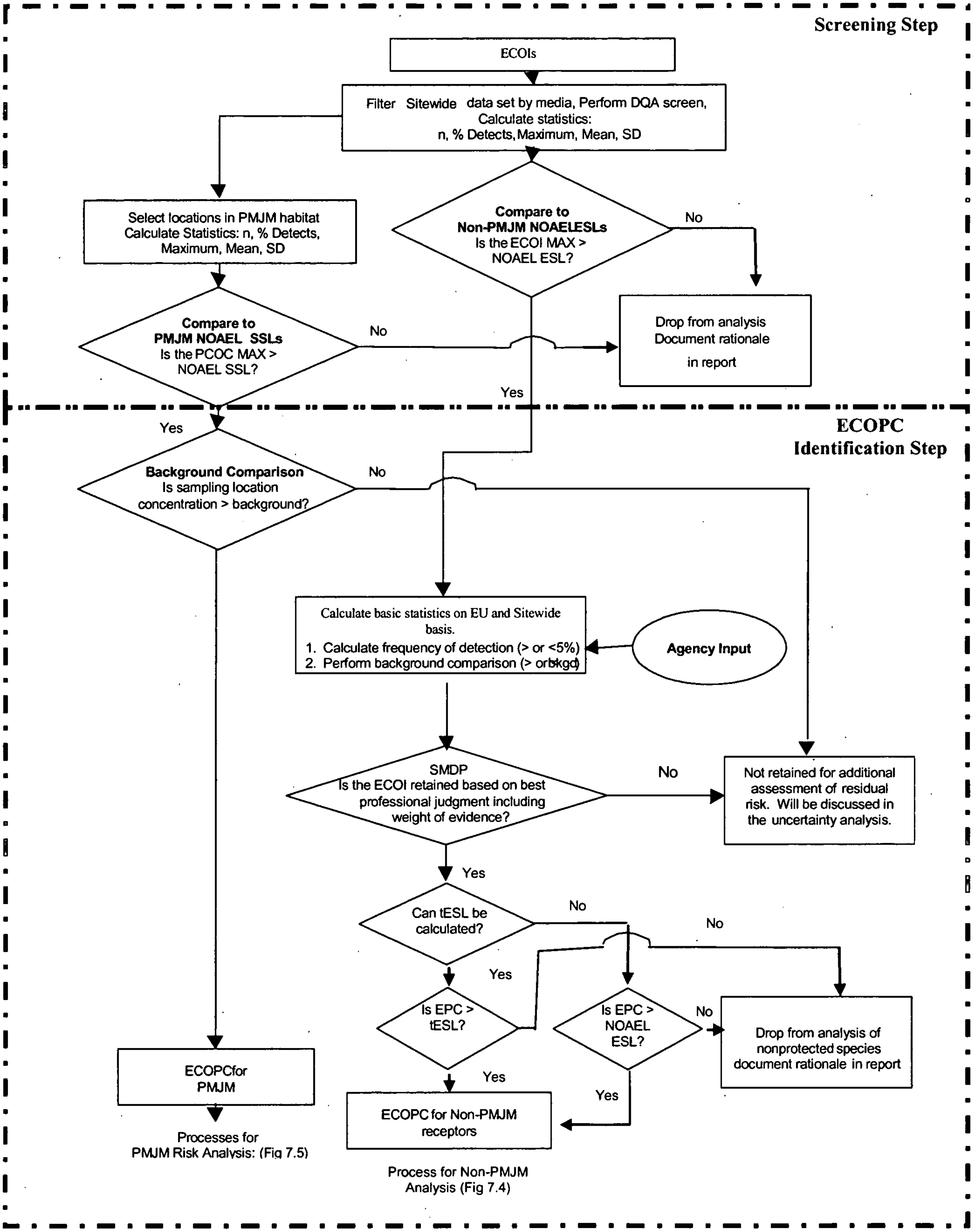
Figure 7.3 Sitewide ECOPC Identification Process



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ECOIs that have detected concentrations greater than the NOAEL-based ESL in the Sitewide data set will undergo further analyses on a Sitewide and EU-specific basis to determine their status as ECOPCs. If the ECOI was detected in less than 5 percent of the samples, the chemical will be evaluated using best professional judgment as to its potential to cause risk to wildlife receptors at the Site. This decision, or scientific management decision point (SMDP), will be made in cooperation with regulatory agency personnel. The determination will consider process knowledge and spatial and temporal factors, as well as the physical and chemical properties of the ECOI as they pertain to the potential for risk to the wildlife receptors at the Site. If it is determined that no potential risk is expected, the ECOI will be dropped from further analysis and the rationale for the decision will be documented in the CRA Report. The radionuclide and metal ECOIs passing the 5 percent screen will then be statistically compared to background concentrations, as appropriate, using the methods discussed in Section 4.4.8.

7.3.1 Non-Preble's Meadow Jumping Mouse Receptors

A determination of whether the tESL can be reliably calculated was conducted (Appendix B). For those ECOIs that have adequate TRV data available, the tESL was calculated using the geometric mean between the NOAEL and the LOAEL ESLs. The tESL will then be used in the ECOPC screening process. For those ECOIs for which no tESL can be calculated, the NOAEL ESL will be used in the final step of the ECOPC screening process.

For the small home range receptors, the 95UCL of the 90th percentile for each EU will be used as the EPC in the final step of the screening process. For the receptors with large home ranges, the sitewide 95UCL of the mean will be used as the EPC in the final step of the screening process.

Any ECOI that fails the final comparison shown on Figure 7.3 will be identified as an ECOPC and carried forward into the risk characterization phase of the CRA. Those ECOIs that pass the final comparison step shown on Figure 7.3 will be dropped from further analysis and documented in the CRA Report.

7.3.2 Preble's Meadow Jumping Mouse Receptors

All ECOIs that exceed the NOAEL SSL for the PMJM within PMJM habitat (that is, 150-foot USFWS buffer) will be compared to background concentrations. If it is determined that concentrations of the ECOI in PMJM habitat do not exceed background concentrations of the ECOI, the ECOI will be reviewed in consultation with the regulatory agencies for removal from the ECOI list. The ECOIs eliminated from further consideration in this step will be documented and discussed in the uncertainty section of the CRA Report. The ECOIs that remain will be carried forward through the background comparison and identified as ECOPCs for the PMJM. The ECOPCs will be discussed in detail in the risk characterization section of the CRA Report.

The output from the Sitewide ECOPC screen will be a list of ECOPCs in PMJM habitat and a list of ECOPCs for nonthreatened or endangered species at the Site. The ECOPCs identified in these lists will be carried forward through the risk characterization process described in the following section. All steps in the process will be documented in the CRA Report.

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7.4 Risk Characterization Process

> **Action:** Assess risks for the PMJM in its habitat areas and other receptors in appropriate areas Sitewide.

The screening-level assessment described earlier defines the process for making preliminary decisions about potential risk, such as the identification of ECOPCs. The risk characterization process will define a range of potential risks to on-site receptors from the ECOPCs.

Characterization of risk will focus on the overall results for each assessment endpoint. The overall risk will be summarized for each receptor group and level of biological organization (that is, individual or population level of protection), as appropriate for the assessment endpoints. As noted by EPA (1997), a well-balanced risk characterization should "...present risk conclusions and information regarding the strengths and limitations of the assessment for other risk assessors, EPA decision-makers, and the public."

Risk characterization has two main components: the risk estimation and the risk description. The risk estimation will summarize results of the analysis, identifying the receptors and ECOPCs and a range of potential risks and the locations/EUs where risk may be present. The risk description will then provide context for the analysis, including the proportions of Sitewide habitats that are affected and interpretation of overall results including data from the Draft Watershed ERA. The risk description will also include overall risk conclusions for each assessment endpoint.

The following sections describe the process for conducting the ecological risk characterization in the CRA for the Site. Two separate approaches will be used in the CRA depending on the status of the habitat designation. The risk characterization process for those areas defined as non-PMJM habitat is presented in Section 7.4.2, while the risk analysis process for the PMJM habitat area is presented in Section 7.4.3.

7.4.1 Definition of Exposure Units and Calculation of Exposure Point Concentrations

Exposures to ecological receptors will be calculated based on the EUs described for human health (Figure 4.1). Wide-ranging species that generally utilize areas larger than the EUs (that is, coyote and mule deer) will also be addressed using Sitewide data. The EUs are reasonable aggregations of common source areas, hydrological systems, and habitat for assessing ecological risk.

For wide-ranging receptors, some high-end intake exposure parameters will be used to estimate exposure to the highly exposed individual rather than the average individual. These parameters are discussed in detail in Appendix B. Risks to these high-end receptors will be evaluated using upper-bound EPCs. EPCs will be estimated using the tiered geospatial approach described in Section 4.6.

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The initial analysis of risks to ecological receptors will use the Tier 1 method of the geospatial approach. Data are treated as if they are randomly located and each sample is weighted equally. The risk calculations based on Tier 1 will tend to be conservative (that is, will tend to overestimate risks) when the data set is biased toward areas with elevated contamination (common at RFETS). If an area is identified as being of potential concern using the Tier 1 approach, then Tier 2, area averaging, will be applied to derive a more realistic estimate of risk.

The Tier 2 approach will be applied as described in Section 4.6. However, the grid means will be used to calculate a 95UCL or estimate the 90th percentile of the distribution of grid means depending on the receptor. The 95UCL of the 90th percentile will also be estimated. Statistical methods described in Section 4.0 will also be applied for the calculation of the ecological EPCs. The Tier 3 kriging approach (Section 4.6) will only be implemented as needed after an initial analysis using Tiers 1 and 2.

For PMJM, sampling locations within PMJM habitat in each EU will be evaluated separately (Section 7.4.3).

7.4.2 Risk Characterization Process for Nonthreatened or Endangered Species Receptors

Risk characterization for non-PMJM receptors will be conducted in the CRA, following the procedures shown on Figure 7.4, for those ECOPCs identified in the screening process described in Section 7.3.

The analyses described in this section apply to all nonthreatened or endangered species. The analysis will be conducted separately for each receptor, based on data on ECOPC concentrations in abiotic media from habitats appropriate for each receptor. Data will be aggregated, as described above from Sitewide samples, and appropriate EPCs will be calculated. Concentrations at each location will be mapped and compared to RFETS background concentrations to determine whether the Site represents incremental risk. If so, additional risk characterization will be performed using additional lines of evidence, such as Site ecological monitoring studies, Draft Watershed ERA data, or other applicable sources to determine whether other data suggest risk.

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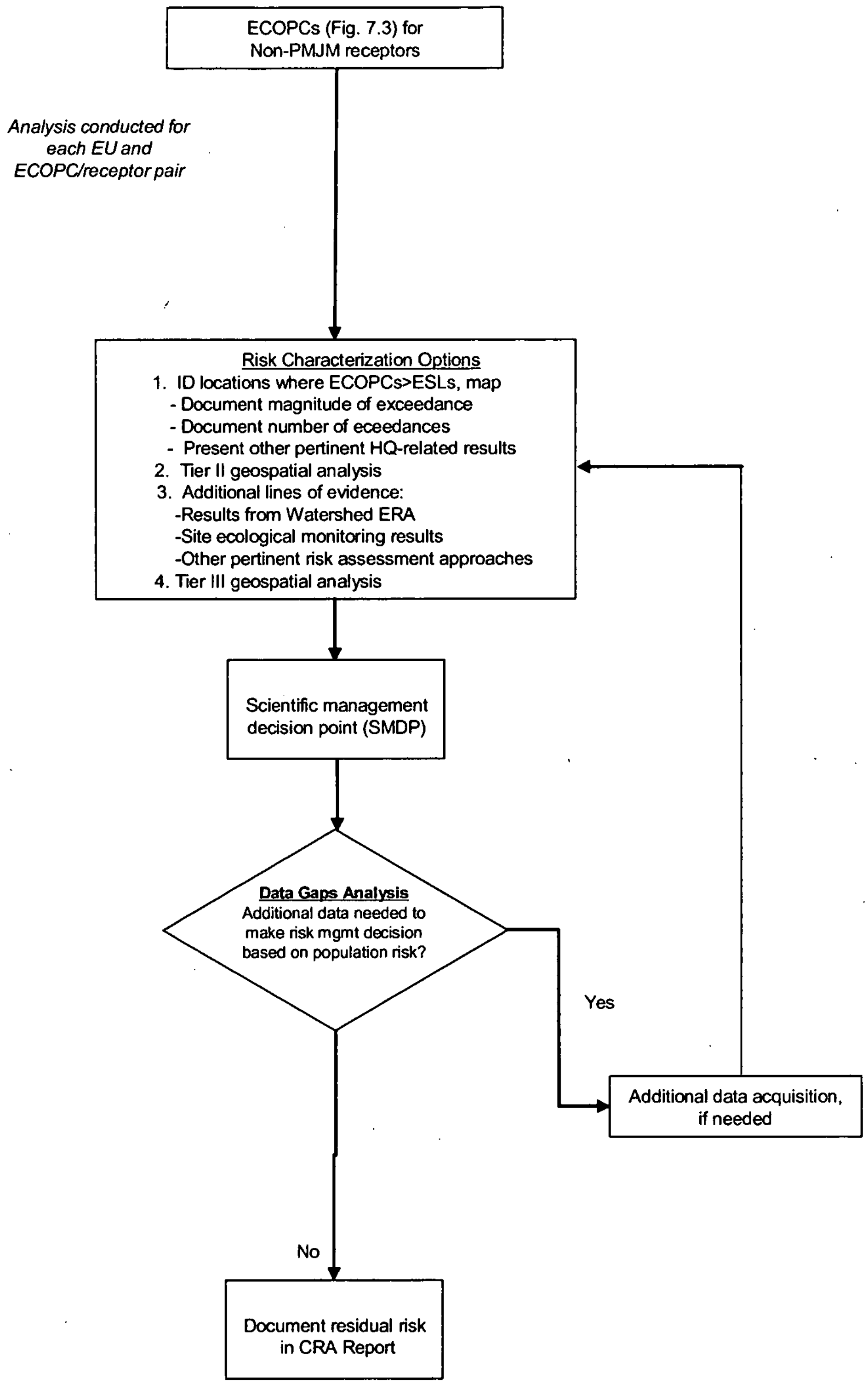
Figure 7.4 CRA Risk Characterization Process for the Non-PMJM Receptor



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An analysis of potential data gaps will be conducted for ECOPCs that represent significant risk. If additional data are deemed to be necessary to reduce the uncertainty in the risk analysis to an acceptable level, the types of data will be identified and acquired.

For exposure scenarios directed at surface soil, data from no deeper than 6 inches will be used. Surface soil samples in the database include a variety of depth intervals (for example, surface scrape, 0 to 2 inches and 0 to 6 inches). Whenever available, the depth intervals for surface soil data will be documented for each location to help interpret risk.

Subsurface soil data (more than 6 inches below the surface) are also available for a variety of depth intervals. Whenever available, the depth intervals from where the data were collected will be specified when assessing subsurface exposures. This information can be used to help determine whether contaminants at depth represent risks to burrowing species.

A detailed evaluation of the uncertainties involved in the risk characterization will also be included in the CRA Report.

7.4.3 Risk Characterization Process for Preble's Jumping Meadow Jumping Mouse Receptor

ECOPCs identified for the PMJM receptor (Figure 7.3) will be subjected to a more conservative risk characterization process than those identified in the non-PMJM habitats due to the regulatory status of the PMJM. Section 7.3 discusses the process to be used to determine the list of ECOPCs to be included in the risk characterization for the PMJM that is shown on Figure 7.5.

The EUs and PMJM habitat are illustrated on Figure 7.6. For each ECOPC identified for risk characterization in the PMJM habitats in each EU, maps will be prepared to identify the sampling locations in PMJM habitat for which ECOPC concentrations exceed the NOAEL-based ESLs and display the magnitude of exceedance of the ESL. Geospatial statistical techniques will be employed to visualize the areas of potential risk to the PMJM. These maps will aid in the identification of habitat patches that will be recommended for further assessment. Concentrations will be compared to RFETS background concentrations to determine whether the location represents additional risk above natural conditions.

These maps will be reviewed in consultation with the regulatory agencies to determine whether additional risk characterization is required. The major goal of the first agency input step is to identify patches of habitat that can be primarily used to aggregate data into groupings that could reasonably be expected to represent home ranges of individual PMJM and identify subpopulations. Aggregated data will be used to calculate upper-bound exposure concentrations.

Based on consultation with the regulatory agencies and best professional judgment, decisions will be made regarding acceptable risk levels for the PMJM. Risks will be categorized as acceptable or unacceptable for the PMJM habitat. The rationale and justification will be documented in the CRA Report. Additional data may also be collected if data gaps are evident. A detailed evaluation of data adequacy will be provided prior to the determination of the potential for risk. The results of this decision point and the uncertainties associated with the potential risk to the PMJM will be discussed in detail in the CRA Report.

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7.4.4 Uncertainty

The objective of the uncertainty analysis for the ERA is to identify and characterize the sources of uncertainty, and the potential effects on risk management decisions for the Site. The uncertainty analysis will also identify the methods by which uncertainty for various sources were accounted for in the analysis. These uncertainties are driven by uncertainty in the Site investigation data, likelihood of hypothetical exposure scenarios, transport modes used to estimate concentrations at receptor locations, receptor intake parameters, and toxicity values used to characterize risk.

Sources of uncertainty can be related to systematic and natural variability and to chemical and physical knowledge. Variable parameters are those that reflect heterogeneity in a well-characterized population, for which the distributions would not generally be narrowed through further measurement or study. Certain parameters reflect a lack of information about the behavior or toxicity of chemicals in the system. The uncertainty analysis for the ERA will be largely qualitative, identifying the primary sources and ranking their potential importance. Quantitative estimates of uncertainty are incorporated through estimates of variability in the data.

Uncertainty will be summarized for the primary components from which different kinds of uncertainty derive: sources of variability (that is, natural and systematic) in data, exposure assessment parameters, uncertainty about ECOPC toxicity thresholds, and the overall risk characterization.

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Figure 7.5 CRA Risk Characterization Process for the PMJM Receptor

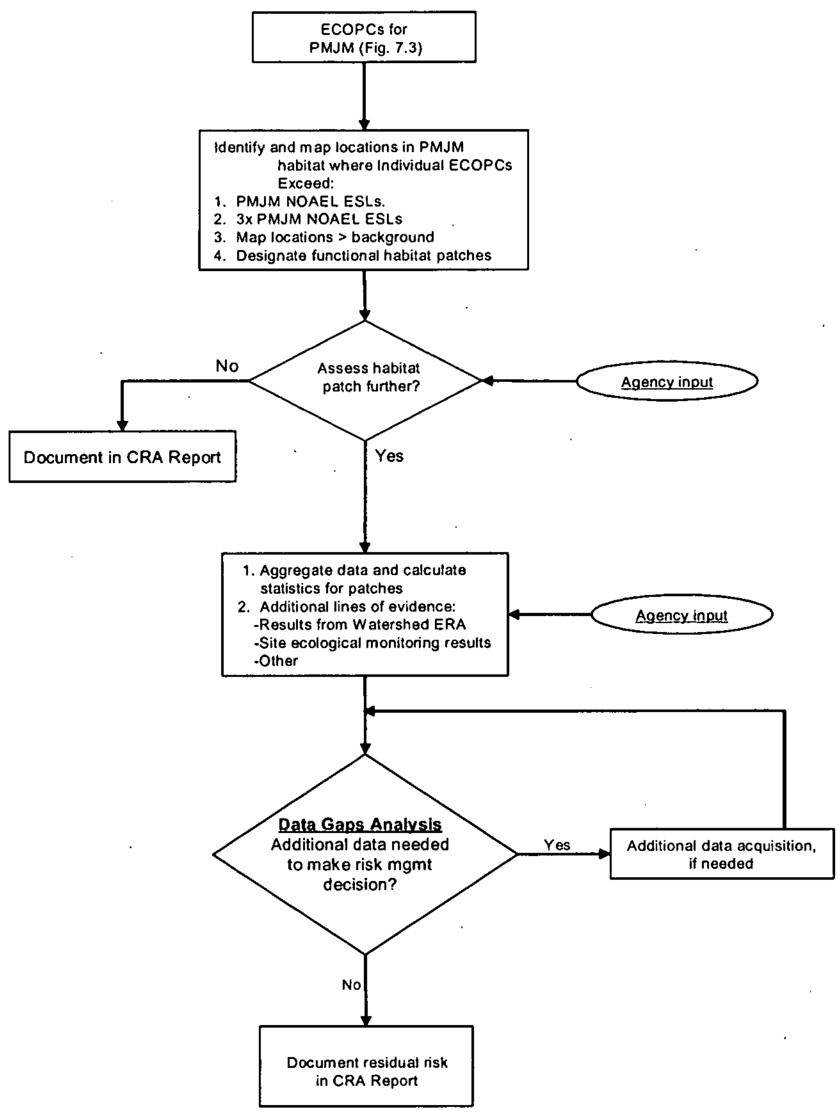

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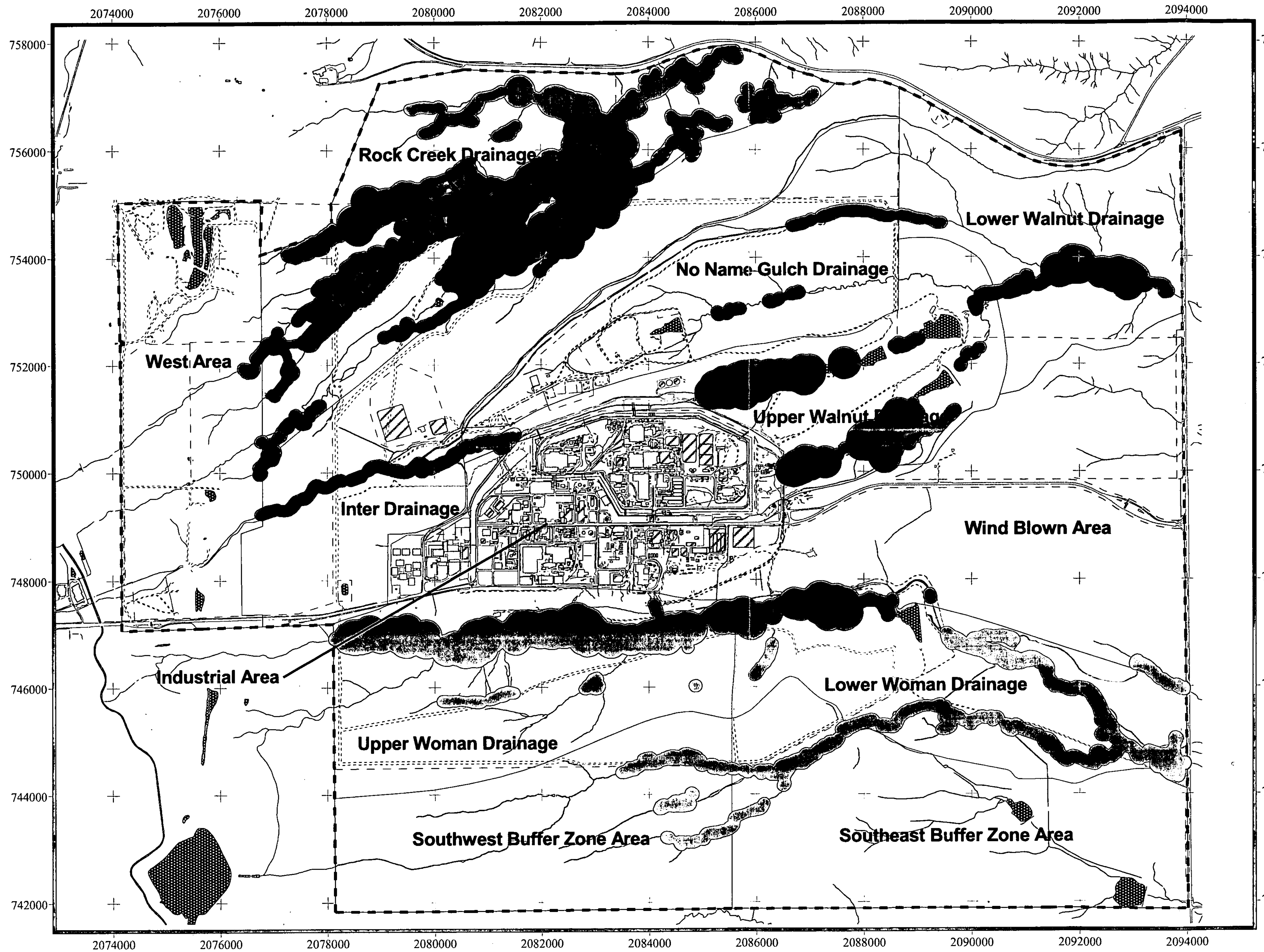
Figure 7.6
Preble's Meadow Jumping Mouse Habitat with Exposure Units



KEY

- PMJM protection area
- Streams, ditches, or other drainage feature
- Paved road
- Dirt road
- Lakes and ponds
- Fence
- Building
  - Demolished
  - Standing
- Site boundary

N W E S

700 0 700 Feet

Scale = 1:27500

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD 27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

Prepared by: Date:04.06.04

RADMS

Prepared for:

KAISER•HILL COMPANY

File:W:\Projects\fy2003\eco\eco_copy.apr\Figure7.6_11x17

8.0 COMPREHENSIVE RISK ASSESSMENT REPORT ORGANIZATION

The Draft CRA Report will contain two volumes: the HHRA and the ERA. Summaries of the HHRA and ERA will be included in the RI/FS text. The full assessments with supporting documentation, will be attached to the RF/FS report as appendices.

The HHRA will contain the following sections:

- Executive Summary;
- Section 1.0 Introduction;
- Section 2.0 Site Description;
- Section 3.0 Data Quality Assessment and Adequacy;
- Section 4.0 COC Identification;
- Section 5.0 Exposure Assessment;
- Section 6.0 Toxicity Assessment;
- Section 7.0 Risk Characterization and Uncertainty Analysis;
- Section 8.0 Summary; and
- Section 9.0 References.

The ERA will contain the following sections:

- Executive Summary;
- Section 1.0 Introduction/Problem Statement;
- Section 2.0 Conceptual Model and Assessment Endpoints;
- Section 3.0 Data Quality Assessment and Adequacy;
- Section 4.0 Risk Characterization and Uncertainty Analysis;
- Section 5.0 Summary; and
- Section 6.0 References.

Appendices for the reports will be combined to reduce redundancy and will include the following:

- Data Summary - Will present data used in both the HHRA and ERA reports; and
- Data Adequacy Assessment.

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8.1 Schedule

The schedule for completion of the CRA is presented in Table 8.1.

Table 8.1 Completion Schedule for the Draft CRA

Task	Description	Dependencies	Deliverable	Completion Date
Complete CRA Work Plan and Methodology (Methodology)	The Methodology guides performance of the CRA. It describes the exposure scenarios and pathways, EUs, DQOS, and exposure assessment methods.	Approval of the methodology includes screening level PRGs for the HHRA, and ESLs for the ERA. The ESLs will also be used in the ecological accelerated action screen. The DAR and the start of the CRA depend on approval of the methodology.	Draft Final CRA Work Plan and Methodology	April 2004
Develop ESLs for ecological receptor.	ESLs are being developed for the analytes listed on Table 3 of Attachment 5 of RFCA	Performance of the ERA as well as accelerated actions, depends on completion of the ESLs.	Draft Ecological ESL Methodology.	April 2004
Data Adequacy Report	Existing data will be analyzed spatially to determine whether additional targeted sampling is required to support the CRA.	Completion of the data adequacy assessment is required to support completion of the Draft CRA. If the data adequacy assessment shows that targeted sampling is required, an addendum to the IA or BZ SAPs will be developed to support a sampling effort during the spring and summer of 2004.	Draft DAR.	May 2004
Ecological Accelerated Action Screen	Site data will be screened for accelerated action using ecological assessment endpoints.	Accelerated actions must be completed so residual risk can be characterized.	None	June 2004
Develop a draft annotated outline of the Draft CRA	The outline will follow the format included in the Draft CRA Methodology. It will describe, in brief form, information that will be included in the Draft CRA.	Subsequent input to the Draft CRA will conform to the annotated outline. It will also be used for the Preliminary Draft IR/FS.	Draft CRA Annotated Outline	May 2004
Complete HHRA/ERA of one EU	Data currently being collected for the 30-acre grid sampling will be used to perform a complete assessment of one of the EUs on the western side of RFETS.	This assessment will be included in the Preliminary Draft RI/FS.	Draft risk assessment of one EU	May 2004
Complete HHRA/ERA for two additional EUs	Data currently being collected for the 30-acre grid sampling will be used to perform assessments for 2 additional EUs	The results will be included in the Draft RI/FS.	Draft risk assessment of two EUs.	August 2004

Table 8.1 Completion Schedule for the Draft CRA

Task	Description	Dependencies	Deliverable	Completion Date
Complete human health assessment for remaining EUs	Additional EUs will be made available for review as they are completed.	All accelerated actions must be completed in the OU; data gap analysis is complete and confirms data adequacy for both human health and ecological receptors.	Draft risk assessments of remaining EUs	October 2004 – June 2005
Complete the Draft CRA	This includes the complete analysis of ecological and human health risk for all EUs from contamination remaining following remedial actions. The assessment will be performed progressively with interim deliverables to be determined but sufficient that the agencies can review analyses prior to issuance of the Draft CRA.	Completion of the Draft CRA requires analysis of the human health and ecological exposure pathways across all EUs. Also, remediation and confirmation sampling needs to be completed to the extent determined adequate by DOE.	Draft CRA	September 2005

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APPENDIX A

Human Health Screening-Level Preliminary Remediation Goals

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ACRONYMS	
AOC	Area of Concern
CAS	Chemical Abstract Service
cm2	square centimeter
COC	contaminant of concern
CRA	Comprehensive Risk Assessment
EU	exposure unit
hr	hour
HQ	hazard quotient
g/mg	grams per milligram
IGD	Implementation Guidance Document
kg	kilogram
kg/m3	kilograms per cubic meter
kg/mg	kilograms per milligram
L/hr	liters per hour
L/day	liters per day
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
m3/day	cubic meters per day
m3/hr	cubic meters per hour
m3/kg	cubic meters per kilogram
mg/cm2	milligrams per square centimeter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
pCi	picocurie
pCi/g	picocuries per gram
pCi/L	picocuries per liter
PRG	preliminary remediation goal
RBC	risk-based concentration
RFCA	Rocky Flats Cleanup Agreement

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ACRONYMS	
RfD	reference dose
RFETS or Site	Rocky Flats Environmental Technology Site
RMA	Rocky Mountain Arsenal
VF	volatilization factor
WRW	wildlife refuge worker
yr	year

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1.0 INTRODUCTION

The preliminary remediation goals (PRGs) for surface soil presented in the Rocky Flats Cleanup Agreement (RFCA) Appendix N of Appendix 3, Implementation Guidance Document (IGD) (DOE et al. 1996 [as modified]), will be used in the Draft Comprehensive Risk Assessment (CRA) for the Rocky Flats Environmental Technology Site (RFETS or Site). Health-based screening-level PRGs are also being developed for this purpose. The screening-level PRGs are being developed for organics, inorganics, and radionuclides in subsurface soil, as well as surface water and groundwater (volatilization pathway). These PRGs will support the derivation of contaminants of concern (COCs) at exposure units (EUs) for the CRA. The PRGs will also support an analysis of the exposure pathways associated with the wildlife refuge worker (WRW). Specifically, the following sets of PRGs are being developed:

- The PRGs for organics, inorganics, and radionuclides in surface soil using the WRW exposure scenario will be used as presented in RFCA, IGD, Appendix N. The PRGs are based on the ingestion, inhalation, and external exposure from surface soil. These PRGs will support the development of surface soil COCs at EUs.
- Screening-level PRGs are being developed for organics, inorganics, and radionuclides in subsurface soil using the WRW exposure scenario. The PRGs are based on the ingestion, inhalation, and external exposure from subsurface soil. These PRGs will support the development of subsurface soil COCs at EUs.
- Screening-level PRGs are being developed for organics, inorganics, and radionuclides in surface water using the WRW exposure scenario. The PRGs are based on the ingestion of surface water. These PRGs will support an assessment of the surface water ingestion pathway, including groundwater contributions.
- Screening-level PRGs are being developed for volatile organics in subsurface soil and groundwater using the WRW exposure scenario. The PRGs being derived are based on the inhalation of volatile organics from subsurface soil and groundwater. These PRGs will support an assessment of volatile organics in subsurface soil and groundwater.

The following sections further discuss the derivation of the screening-level PRGs, along with the applicable exposure parameters, PRG equations, and PRG values. The screening-level PRGs were derived using these PRG equations with the applicable PRG parameters. A description of the derivation of the surface soil PRGs is presented in RFCA, IGD, Appendix N. Toxicity factors, including inhalation and ingestion slope factors and reference doses (RfDs), are also found in Appendix N.

1.1 Subsurface Soil Screening-Level PRGs

The WRW subsurface soil exposure scenario consists of the following pathways: ingestion of surface soil, inhalation of dust (outdoors), and dermal contact for nonradionuclides for a WRW working at the Site for an average of 18.7 years, spending 20 days per year, 4 hours per day exposed to subsurface soil. Inhalation of volatiles is not assessed. The external radiation exposure pathway is also included for radionuclides. The scenario assumes the

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worker will be performing soil contact-intensive activities. This scenario includes all complete and significant exposure pathways and parameter assumptions that were evaluated in the Task 3 Report and Appendices: Calculation of Surface Radionuclide Soil Action Levels for Plutonium, Americium, and Uranium (EPA et al. 2002). PRGs were calculated for both a 1 x 10^{-6} risk and a hazard quotient (HQ) of 0.1. The more conservative of the two values is chosen for the PRG.

1.1.1 PRG Parameters

The PRG parameters listed in Table 1.1 are used to derive PRGs using the PRG equations presented in Section 1.1.2.

Table 1.1
PRG Parameters for Subsurface Soil Screen

Exposure Parameter	Variable	Unit	Point Estimate
Target hazard index	THI-1	--	0.1
Target excess lifetime cancer risk	TR-1	--	1E-06
Adult body weight	BWa	kg	70
Averaging time - noncarcinogenic	ATnc	yr	18.7
Averaging time - carcinogenic	ATc	yr	70
Exposure frequency	EFwsubs	day/yr	20
Exposure duration	EDw	yr	18.7
Exposure time-outdoors	ETo_w	hr/day	4
Hourly inhalation rate (adult worker)	IRaw	m^3/hr	1.30
Mass loading, (PM10) for inhalation	MLF	kg/m^3	6.7 E-8
Site-specific PEF based on ML	PEF	m^3/kg	14925373
Soil ingestion rate	IRwss	mg/day	100
Exposure time fraction, outdoor	ETFo_w	--	1
Exposure time fraction, indoor	ETFi_w	--	0
WRW skin-soil adherence factor	AFw	mg/cm^2-event	0.117
Event frequency	EVw	events/day	1
WRW skin surface area	SAw	cm^2	3300
Dermal absorption fraction	ABS	--	chemical-specific
Gamma shielding factor (1-Se)	GSF	--	0
Area correction factor	ACF	--	0.9
Oral reference dose	RfDo	mg/kg-day	chemical-specific
Oral cancer slope factor	CSFo	$(mg/kg\text{-}day)^{-1}$	chemical-specific
Inhalation reference dose	RfDi	mg/kg-day	chemical-specific
Inhalation cancer slope factor	CSFi	$(mg/kg\text{-}day)^{-1}$	chemical-specific
Oral soil cancer slope factor - radionuclides	CSFsoil	risk/pCi	radionuclide-specific
External cancer slope factor - radionuclides	CSFe	risk/yr/pCi/g	radionuclide-specific

1.1.2 PRG Equations

The following PRG equations are used to derive the PRG values:

Noncarcinogenic PRG =

((THI x ATnc(yr) x 365(day/yr)) / (IRwss(mg/day) x EFwsubs(day/yr) x EDw(yr) x 10^{-6} (kg/mg) x 1/RfDo(mg/kg-day) x 1/BWa(kg))) + (IRaw(m^3/hr) x EFwsubs(day/year) x EDw(yr) x ETo_w(hr/day) x 1/PEF*(m^3/kg) x 1/RfDi(mg/kg-day) x 1/BWa(kg) x (ETFo_w + (ETFi_w))) + (SAw(cm^2) x AFw(mg/cm^2-event) x EFwsubs(day/yr) x EDw(yr) x ABS x EVw(events/day) x 1/RfDo(mg/kg-day) x 10^{-6}(kg/mg) x 1/BWa(kg))

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Carcinogenic PRG =

((TR x ATc(yr) x 365(day/yr)) / (IRwss(mg/day) x EFwsubs(day/yr) x EDw(yr) x 10^{-6} (kg/mg) x CSFo(risk/mg/kg-day) x 1/BWa(kg))) + (IRaw(m^3/hr) x EFwsubs(day/yr) x EDw(yr) x ETo_w(hr/day) x 1/PEF*(m^3/kg) x CSFi(risk/mg/kg-day) x 1/BWa(kg) x (ETFo_w + (ETFi_w))) + (SAw(cm^2) x AFw(mg/cm^2-event) x EFwsubs(day/yr) x EDw(yr) x ABS x EVw(events/day) x CSFo(risk/mg/kg-day) x 10^{-6}(kg/mg) x 1/BWa(kg))

Radionuclide Carcinogenic PRG =

(TR / (IRwss(mg/day) x CSFsoil(risk/pCi) x 10^{-3}(g/mg) x EFwsubs(day/yr) x EDw(yr)) + (IRaw(m^3/hr) x 1/PEF(m^3/kg) x CSFi(risk/pCi) x 1000(g/kg) x EFwsubs(day/yr) x EDw(yr) x ETo_w(hr/day) x (ETFo_w + ETFi_w))) + (CSFe(risk/yr/pCi/g) x EF_wsubs(day/yr)/365(day/yr) x ETo_w(hr/day)/24 x ED_w(yr) x ACF)

1.1.3 Subsurface Soil Screening-Level PRG Values

Table 1.2 presents the subsurface soil screening-level PRG values.

Table 1.2
Subsurface Soil Screening Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker Noncarcinogenic Subsoil RBC HQ = 0.1 (mg/kg)	Wildlife Refuge Worker Carcinogenic Subsoil RBC Risk = 1E-06 (mg/kg)	Wildlife Refuge Worker Subsurface Soil Risk = 1E-06 or HQ = 0.1 (mg/kg)
Acenaphthene	83-32-9	5.10E+04		5.10E+04
Acetone	67-64-1	1.28E+05		1.28E+05
Aldrin	309-00-2	2.76E+01	2.02E+00	2.02E+00
Aluminum	7429-90-5	2.85E+05		2.85E+05
Anthracene	120-12-7	2.55E+05		2.55E+05
Antimony	7440-36-0	5.11E+02		5.11E+02
Aroclor 1016	12674-11-2	5.80E+01	4.42E+02	5.80E+01
Aroclor 1221	11104-28-2		1.55E+01	1.55E+01
Aroclor 1232	11141-16-5		1.55E+01	1.55E+01
Aroclor 1242	53469-21-9		1.55E+01	1.55E+01
Aroclor 1248	12672-29-6		1.55E+01	1.55E+01
Aroclor 1254	11097-69-1	1.66E+01	1.55E+01	1.55E+01
Aroclor 1260	11096-82-5		1.55E+01	1.55E+01
Arsenic	7440-38-2	3.43E+02	2.77E+01	2.77E+01
Barium	7440-39-3	3.30E+04		3.30E+04
Benzene	71-43-2	4.26E+02	2.57E+02	2.57E+02
alpha-BHC	319-84-6		6.56E+00	6.56E+00
beta-BHC	319-85-7		2.29E+01	2.29E+01
delta-BHC	319-86-8			
gamma-BHC (Lindane)	58-89-9	3.32E+02	3.19E+01	3.19E+01
Benzo(a)anthracene	56-55-3		4.36E+01	4.36E+01
Benzo(a)pyrene	50-32-8		4.36E+00	4.36E+00
Benzo(b)fluoranthene	205-99-2		4.36E+01	4.36E+01
Benzo(k)fluoranthene	207-08-9		4.36E+02	4.36E+02
Benzoic Acid (at pH 7)	65-85-0	5.11E+06		5.11E+06
Benzyl Alcohol	100-51-6	3.83E+05		3.83E+05
Beryllium	7440-41-7	1.15E+03	1.63E+03	1.15E+03
bis(2-chloroethyl)ether	111-44-4		4.35E+01	4.35E+01

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Table 1.2
Subsurface Soil Screening Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Subsoil RBC HQ = 0.1 (mg/kg)	Carcinogenic Subsoil RBC Risk = 1E-06 (mg/kg)	Subsurface Soil Risk = 1E-06 or HQ = 0.1 (mg/kg)
bis(2-chloroisopropyl)ether	39638-32-9	5.11E+04	6.83E+02	6.83E+02
bis(2-ethylhexyl)phthalate	117-81-7	1.84E+04	2.46E+03	2.46E+03
Bromodichloromethane	75-27-4	2.56E+04	7.71E+02	7.71E+02
Bromoform	75-25-2	2.56E+04	4.66E+03	4.66E+03
Bromomethane (methyl bromide)	74-83-9	2.41E+02		2.41E+02
2-Butanone (methyl ethyl ketone)	78-93-3	2.41E+05		2.41E+05
Butylbenzylphthalate	85-68-7	1.84E+05		1.84E+05
Cadmium (water)	7440-43-9	6.39E+02	2.18E+03	6.39E+02
Cadmium (food)	7440-43-9	1.20E+03	2.18E+03	1.20E+03
Carbon disulfide	75-15-0	1.88E+04		1.88E+04
Carbon tetrachloride	56-23-5	1.02E+02	1.03E+02	1.02E+02
alpha-Chlordane	5103-71-9	5.49E+02	1.18E+02	1.18E+02
beta-Chlordane	5103-74-2	5.49E+02	1.18E+02	1.18E+02
gamma-Chlordane	12789-03-6	5.49E+02	1.18E+02	1.18E+02
4-Chloroaniline	106-47-8	3.69E+03		3.69E+03
Chlorobenzene	108-90-7	7.61E+03		7.61E+03
Chloroethane (ethyl chloride)	75-00-3	1.11E+05	1.65E+04	1.65E+04
Chloroform	67-66-3	2.40E+01	1.30E+02	2.40E+01
Chloromethane (methyl chloride)	74-87-3	1.29E+03	4.64E+02	4.64E+02
2-Chloronaphthalene	91-58-7	1.02E+05		1.02E+05
2-Chlorophenol	95-57-8	6.39E+03		6.39E+03
Chromium III	16065-83-1	1.92E+06		1.92E+06
Chromium VI	18540-29-9	2.84E+03	3.35E+02	3.35E+02
Chrysene	218-01-9		4.36E+03	4.36E+03
Cobalt	7440-48-4	1.93E+03		1.93E+03
Copper	7440-50-8	5.11E+04		5.11E+04
Cyanide	57-12-5	2.56E+04		2.56E+04
4,4-DDD	72-54-8		1.79E+02	1.79E+02
4,4-DDE	72-55-9		1.26E+02	1.26E+02
4,4-DDT	50-29-3	5.72E+02	1.26E+02	1.26E+02
Dibenz(a,h)anthracene	53-70-3		4.36E+00	4.36E+00
Dibenzofuran	132-64-9	3.69E+03		3.69E+03
Dibromochloromethane	124-48-1	1.84E+04	4.11E+02	4.11E+02
Di-n-butylphthalate	84-74-2	9.22E+04		9.22E+04
1,2-Dichlorobenzene (o-)	95-50-1	3.90E+04		3.90E+04
1,4-Dichlorobenzene (p-)	106-46-7	3.40E+04	1.05E+03	1.05E+03
3,3-Dichlorobenzidine	91-94-1		7.67E+01	7.67E+01
1,1-Dichloroethane	75-34-3	2.81E+04		2.81E+04
1,2-Dichloroethane	107-06-2	5.93E+02	1.32E+02	1.32E+02
1,1-Dichloroethene	75-35-4	1.15E+04	2.13E+01	2.13E+01
1,2-Dichloroethene (total)	540-59-0	1.15E+04		1.15E+04
2,4-Dichlorophenol (at pH 6.8)	120-83-2	3.83E+03		3.83E+03
1,2-Dichloropropane	78-87-5	4.32E+02	7.03E+02	4.32E+02
cis-1,3-Dichloropropene	10061-01-5	1.22E+04	8.21E+00	8.21E+00
trans-1,3-Dichloropropene	10061-02-6	1.22E+04	8.21E+00	8.21E+00
Dieldrin	60-57-1	4.61E+01	2.15E+00	2.15E+00
Diethylphthalate	84-66-2	7.37E+05		7.37E+05
2,4-Dimethylphenol	105-67-9	2.56E+04		2.56E+04
Dimethylphthalate	131-11-3	9.22E+06		9.22E+06
4,6-Dinitro-2-methylphenol (4,6-	534-52-1	1.28E+03		1.28E+03

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Table 1.2
Subsurface Soil Screening Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Subsoil RBC HQ = 0.1 (mg/kg)	Carcinogenic Subsoil RBC Risk = 1E-06 (mg/kg)	Subsurface Soil Risk = 1E-06 or HQ = 0.1 (mg/kg)
dinitro-o-cresol)				
2,4-Dinitrophenol	51-28-5	2.56E+03		2.56E+03
2,4-Dinitrotoluene	121-14-2	2.56E+03	7.03E+01	7.03E+01
2,6-Dinitrotoluene	606-20-2	1.28E+03	7.03E+01	7.03E+01
Di-n-octylphthalate	117-84-0	1.84E+04	9.80E+05	1.84E+04
Endosulfan I	959-98-8	5.53E+03		5.53E+03
Endosulfan II	33213-65-9	5.53E+03		5.53E+03
Endosulfan sulfate	1031-07-8	5.53E+03		5.53E+03
Endosulfan (technical)	115-29-7	5.53E+03		5.53E+03
Endrin (technical)	72-20-8	2.76E+02		2.76E+02
Ethylbenzene	100-41-4	7.02E+04	5.31E+03	5.31E+03
Fluoranthene	206-44-0	3.40E+04		3.40E+04
Fluorene	86-73-7	5.10E+04		5.10E+04
Heptachlor	76-44-8	4.61E+02	7.65E+00	7.65E+00
Heptachlor epoxide	1024-57-3	1.20E+01	3.78E+00	3.78E+00
Hexachlorobenzene	118-74-1	7.37E+02	2.15E+01	2.15E+01
Hexachlorobutadiene	87-68-3	1.84E+02	4.41E+02	1.84E+02
Hexachlorocyclopentadiene	77-47-4	4.37E+03		4.37E+03
Hexachloroethane	67-72-1	9.22E+02	2.46E+03	9.22E+02
Indeno(1,2,3-cd)pyrene	193-39-5		4.36E+01	4.36E+01
Iron	7439-89-6	3.83E+05		3.83E+05
Isophorone	78-59-1	1.84E+05	3.63E+04	3.63E+04
Lead	7439-92-1			
Lithium	7439-93-2	2.56E+04		2.56E+04
Magnesium	7439-95-4			
Manganese (nonfood)	7439-96-5	4.35E+03		4.35E+03
Mercury (elemental)	7439-97-6	3.15E+04		3.15E+04
Methoxychlor	72-43-5	6.39E+03		6.39E+03
Methylene chloride (dichloromethane)	75-09-2	5.79E+04	3.16E+03	3.16E+03
2-Methylnaphthalene	91-57-6	2.56E+04		2.56E+04
4-Methyl-2-pentanone (methyl isobutyl ketone)	108-10-1	2.05E+04		2.05E+04
2-Methylphenol (o-cresol)	95-48-7	4.61E+04		4.61E+04
4-Methylphenol (p-cresol)	106-44-5	4.61E+03		4.61E+03
Molybdenum	7439-98-7	6.39E+03		6.39E+03
Naphthalene	91-20-3	3.87E+03		3.87E+03
Nickel (soluble)	7440-02-0	2.56E+04		2.56E+04
2-Nitroaniline	88-74-4	2.09E+04		2.09E+04
Nitrobenzene	98-95-3	4.15E+02		4.15E+02
4-Nitrophenol	100-02-7	1.02E+04		1.02E+04
n-Nitrosodiphenylamine	86-30-6		9.76E+03	9.76E+03
n-Nitrosodipropylamine	621-64-7		6.83E+00	6.83E+00
Pentachlorophenol	87-86-5	1.95E+04	2.03E+02	2.03E+02
Phenol	108-95-2	7.67E+05		7.67E+05
Pyrene	129-00-0	2.76E+04		2.76E+04
Selenium	7782-49-2	6.39E+03		6.39E+03
Silver	7440-22-4	6.39E+03		6.39E+03
Strontium	7440-24-6	7.67E+05		7.67E+05
Styrene	100-42-5	1.54E+05		1.54E+05

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Table 1.2
Subsurface Soil Screening Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Subsoil RBC HQ = 0.1 (mg/kg)	Carcinogenic Subsoil RBC Risk = 1E-06 (mg/kg)	Subsurface Soil Risk = 1E-06 or HQ = 0.1 (mg/kg)
1,1,2,2-Tetrachloroethane	79-34-5	7.67E+04	1.25E+02	1.25E+02
Tetrachloroethene	127-18-4	1.28E+04	7.68E+02	7.68E+02
Tin	7440-31-5	7.67E+05		7.67E+05
Toluene	108-88-3	3.91E+04		3.91E+04
Toxaphene	8001-35-2		3.13E+01	3.13E+01
1,2,4-Trichlorobenzene	120-82-1	1.15E+04		1.15E+04
1,1,1-Trichloroethane	71-55-6	9.97E+04		9.97E+04
1,1,2-Trichloroethane	79-00-5	5.11E+03	2.95E+02	2.95E+02
Trichloroethene	79-01-6	3.43E+02	2.45E+01	2.45E+01
2,4,5-Trichlorophenol	95-95-4	1.28E+05		1.28E+05
2,4,6-Trichlorophenol	88-06-2		4.33E+03	4.33E+03
Uranium (soluble salts)	7440-61-1	3.83E+03		3.83E+03
Vanadium	7440-62-2	8.94E+03		8.94E+03
Vinyl acetate	108-05-4	1.20E+06		1.20E+06
Vinyl chloride	75-01-4	1.56E+03	5.15E+01	5.15E+01
Xylene (total)	1330-20-7	2.56E+06		2.56E+06
Zinc	7440-66-6	3.83E+05		3.83E+05
Nitrate	14797-55-8	2.04E+06		2.04E+06
Nitrite	14797-65-0	1.28E+05		1.28E+05
Ammonium (as Ammonia)	7664-41-7	1.05E+07		1.05E+07
Fluoride (as fluorine)	7782-41-4	7.67E+04		7.67E+04
		pCi/g	pCi/g	pCi/g
Am-241	14596-10-2		6.24E+01	6.24E+01
Pu-239	15117-48-3		6.79E+01	6.79E+01
Pu-240	14119-33-6		6.80E+01	6.80E+01
U-233	13968-55-3	3.83E+03	1.31E+02	1.31E+02
U-234	13966-29-5	3.83E+03	1.35E+02	1.35E+02
U-235	15117-96-1	3.83E+03	1.15E+01	1.15E+01
U-235+D	15117-96-1(+D)	3.83E+03	1.10E+01	1.10E+01
U-238	7440-61-1	3.83E+03	1.52E+02	1.52E+02
U-238+D	7440-61-1(+D)	3.83E+03	3.76E+01	3.76E+01

1.2 Surface Water Screening-Level PRGs

The WRW surface water exposure scenario consists of the following pathway: ingestion of surface water on the Site for 18.7 years while performing outdoor tasks near surface water. The scenario assumes the WRW may incidentally ingest surface water while performing biological surveying tasks 42 days per year (EBASCO 1993). This scenario was not considered to be a significant exposure pathway in the Task 3 Report and Appendices: Calculation of Surface Radionuclide Soil Action Levels for Plutonium, Americium, and Uranium (EPA et al. 2002). Calculations in this appendix were performed deterministically. PRGs were calculated for both a 1 x 10^{-6} risk and an HQ of 0.1.

1.2.1 PRG Parameters

The PRG parameters presented in Table 1.3 were used to derive PRGs using the PRG equations listed in Section 1.2.2.

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Table 1.3
PRG Parameters for Surface Water Screen

Exposure Parameter	Variable	Unit	Point Estimate
Target hazard index	THI	--	0.1
Target excess lifetime cancer risk	TR	--	1E-06
Adult body weight	BWa	kg	70
Averaging time - noncarcinogenic	ATnc	yr	18.7
Averaging time - carcinogenic	ATc	yr	70
Exposure time - surface water	ETwsw	hr/day	1
Exposure frequency - surface water[a]	EFwsw	day/yr	42
Exposure duration	EDw	yr	18.7
Surface water incidental ingestion rate[b]	IRsw	L/hr	0.03
Oral reference dose	RfDo	mg/kg-day	chemical-specific
Oral cancer slope factor	CSFo	risk/(mg/kg-day)	chemical-specific
Water ingestion slope factor - radionuclides	CSFSw	risk/pCi	radionuclide-specific

a. Value estimated from Table B.2 att 3-1(RMA IEA/RC Appendix B, 8/25/93).
b. EPA, 1998

1.2.2 PRG Equations

The following PRG equations are used to derive the PRG values:

Noncarcinogenic PRG =

((THI x ATnc(yr) x 365(day/yr))/(IRsw(L/hr) x ETwsw(hr/day) x EFwsw(day/yr) x EDw(yr) x 1/RfDo(mg/kg-day) x 1/BWa(kg)))

Carcinogenic PRG =

((TR x ATc(yr) x 365(day/yr))/(IRsw(L/hr) x ETwsw(hr/day) x EFwsw(day/yr) x EDw(yr) x CSFo(risk/mg/kg-day) x (1/BWa(kg)))

Radionuclide Carcinogenic PRG =

(TR/(IRsw(L/hr) x ETwsw(hr/day) x EFwsw(day/yr) x EDw(yr) x CSFw (risk/pCi))

1.2.3 Surface Water Screening-Level PRG Values

Table 1.4 presents the surface water screening-level PRG values.

Table 1.4
Surface Water Screening-Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Surface Water HQ = 0.1 (mg/L)	Carcinogenic Surface Water Risk = 1E-06 (mg/L)	Surface Water Risk = 1E-06 or HQ = 0.1 (mg/L)
Acenaphthene	83-32-9	1.22E+02		1.22E+02
Acetone	67-64-1	2.03E+02		2.03E+02
Aldrin	309-00-2	6.08E-02	4.47E-03	4.47E-03
Aluminum	7429-90-5	2.03E+03		2.03E+03
Anthracene	120-12-7	6.08E+02		6.08E+02
Antimony	7440-36-0	8.11E-01		8.11E-01
Aroclor 1016	12674-11-2	1.42E-01	1.08E+00	1.42E-01
Aroclor 1221	11104-28-2		3.80E-02	3.80E-02
Aroclor 1232	11141-16-5		3.80E-02	3.80E-02

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Table 1.4
Surface Water Screening-Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Surface Water HQ = 0.1 (mg/L)	Carcinogenic Surface Water Risk = 1E-06 (mg/L)	Surface Water Risk = 1E-06 or HQ = 0.1 (mg/L)
Aroclor 1242	53469-21-9		3.80E-02	3.80E-02
Aroclor 1248	12672-29-6		3.80E-02	3.80E-02
Aroclor 1254	11097-69-1	4.06E-02	3.80E-02	3.80E-02
Aroclor 1260	11096-82-5		3.80E-02	3.80E-02
Arsenic	7440-38-2	6.08E-01	5.06E-02	5.06E-02
Barium	7440-39-3	1.42E+02		1.42E+02
Benzene	71-43-2	6.08E+00	1.38E+00	1.38E+00
alpha-BHC	319-84-6		1.20E-02	1.20E-02
beta-BHC	319-85-7		4.22E-02	4.22E-02
delta-BHC	319-86-8			
gamma-BHC (Lindane)	58-89-9	6.08E-01	5.84E-02	5.84E-02
Benzo(a)anthracene	56-55-3		1.04E-01	1.04E-01
Benzo(a)pyrene	50-32-8		1.04E-02	1.04E-02
Benzo(b)fluoranthene	205-99-2		1.04E-01	1.04E-01
Benzo(k)fluoranthene	207-08-9		1.04E+00	1.04E+00
Benzoic Acid (at pH 7)	65-85-0	8.11E+03		8.11E+03
Benzyl Alcohol	100-51-6	6.08E+02		6.08E+02
Beryllium	7440-41-7	4.06E+00		4.06E+00
bis(2-chloroethyl)ether	111-44-4		6.90E-02	6.90E-02
bis(2-chloroisopropyl)ether	39638-32-9	8.11E+01	1.08E+00	1.08E+00
bis(2-ethylhexyl)phthalate	117-81-7	4.06E+01	5.42E+00	5.42E+00
Bromodichloromethane	75-27-4	4.06E+01	1.22E+00	1.22E+00
Bromoform	75-25-2	4.06E+01	9.61E+00	9.61E+00
Bromomethane (methyl bromide)	74-83-9	2.84E+00		2.84E+00
2-Butanone (methyl ethyl ketone)	78-93-3	1.22E+03		1.22E+03
Butylbenzylphthalate	85-68-7	4.06E+02		4.06E+02
Cadmium (food)	7440-43-9			
Cadmium (water)	7440-43-9	1.01E+00		1.01E+00
Carbon disulfide	75-15-0	2.03E+02		2.03E+02
Carbon tetrachloride	56-23-5	1.42E+00	5.84E-01	5.84E-01
alpha-Chlordane	5103-71-9	1.01E+00	2.17E-01	2.17E-01
beta-Chlordane	5103-74-2	1.01E+00	2.17E-01	2.17E-01
gamma-Chlordane	12789-03-6	1.01E+00	2.17E-01	2.17E-01
4-Chloroaniline	106-47-8	8.11E+00		8.11E+00
Chlorobenzene	108-90-7	4.06E+01		4.06E+01
Chloroethane (ethyl chloride)	75-00-3	8.11E+02	2.62E+01	2.62E+01
Chloroform	67-66-3	2.03E+01		2.03E+01
Chloromethane (methyl chloride)	74-87-3		5.84E+00	5.84E+00
2-Chloronaphthalene	91-58-7	1.62E+02		1.62E+02
2-Chlorophenol	95-57-8	1.01E+01		1.01E+01
Chromium III	16065-83-1	3.04E+03		3.04E+03
Chromium VI	18540-29-9	6.08E+00		6.08E+00
Chrysene	218-01-9		1.04E+01	1.04E+01
Cobalt	7440-48-4	4.06E+01		4.06E+01
Copper	7440-50-8	8.11E+01		8.11E+01
Cyanide	57-12-5	4.06E+01		4.06E+01
4,4-DDD	72-54-8		3.16E-01	3.16E-01
4,4-DDE	72-55-9		2.23E-01	2.23E-01
4,4-DDT	50-29-3	1.01E+00	2.23E-01	2.23E-01
Dibenz(a,h)anthracene	53-70-3		1.04E-02	1.04E-02
Dibenzofuran	132-64-9	8.11E+00		8.11E+00

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Table 1.4
Surface Water Screening-Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Surface Water HQ = 0.1 (mg/L)	Carcinogenic Surface Water Risk = 1E-06 (mg/L)	Surface Water Risk = 1E-06 or HQ = 0.1 (mg/L)
Dibromochloromethane	124-48-1	4.06E+01	9.04E-01	9.04E-01
Di-n-butylphthalate	84-74-2	2.03E+02		2.03E+02
1,2-Dichlorobenzene (o-)	95-50-1	1.83E+02		1.83E+02
1,4-Dichlorobenzene (p-)	106-46-7	6.08E+01	3.16E+00	3.16E+00
3,3-Dichlorobenzidine	91-94-1		1.69E-01	1.69E-01
1,1-Dichloroethane	75-34-3	2.03E+02		2.03E+02
1,2-Dichloroethane	107-06-2	6.08E+01	8.34E-01	8.34E-01
1,1-Dichloroethene	75-35-4	1.83E+01	1.27E-01	1.27E-01
1,2-Dichloroethene (total)	540-59-0	1.83E+01		1.83E+01
2,4-Dichlorophenol (at pH 6.8)	120-83-2	6.08E+00		6.08E+00
1,2-Dichloropropane	78-87-5		1.12E+00	1.12E+00
cis-1,3-Dichloropropene	10061-01-5	6.08E+01	7.59E-01	7.59E-01
trans-1,3-Dichloropropene	10061-02-6	6.08E+01	7.59E-01	7.59E-01
Dieldrin	60-57-1	1.01E-01	4.74E-03	4.74E-03
Diethylphthalate	84-66-2	1.62E+03		1.62E+03
2,4-Dimethylphenol	105-67-9	4.06E+01		4.06E+01
Dimethylphthalate	131-11-3	2.03E+04		2.03E+04
4,6-Dinitro-2-methylphenol (4,6-dinitro-o-cresol)	534-52-1	2.03E+00		2.03E+00
2,4-Dinitrophenol	51-28-5	4.06E+00		4.06E+00
2,4-Dinitrotoluene	121-14-2	4.06E+00	1.12E-01	1.12E-01
2,6-Dinitrotoluene	606-20-2	2.03E+00	1.12E-01	1.12E-01
Di-n-octylphthalate	117-84-0	4.06E+01		4.06E+01
Endosulfan I	959-98-8	1.22E+01		1.22E+01
Endosulfan II	33213-65-9	1.22E+01		1.22E+01
Endosulfan sulfate	1031-07-8	1.22E+01		1.22E+01
Endosulfan (technical)	115-29-7	1.22E+01		1.22E+01
Endrin (technical)	72-20-8	6.08E-01		6.08E-01
Ethylbenzene	100-41-4	2.03E+02		2.03E+02
Fluoranthene	206-44-0	8.11E+01		8.11E+01
Fluorene	86-73-7	1.22E+02		1.22E+02
Heptachlor	76-44-8	1.01E+00	1.69E-02	1.69E-02
Heptachlor epoxide	1024-57-3	2.64E-02	8.34E-03	8.34E-03
Hexachlorobenzene	118-74-1	1.62E+00	4.74E-02	4.74E-02
Hexachlorobutadiene	87-68-3	4.06E-01	9.73E-01	4.06E-01
Hexachlorocyclopentadiene	77-47-4	1.22E+01		1.22E+01
Hexachloroethane	67-72-1	2.03E+00	5.42E+00	2.03E+00
Indeno(1,2,3-cd)pyrene	193-39-5		1.04E-01	1.04E-01
Iron	7439-89-6	6.08E+02		6.08E+02
Isophorone	78-59-1	4.06E+02	7.99E+01	7.99E+01
Lead	7439-92-1			4.00E+02
Lithium	7439-93-2	4.06E+01		4.06E+01
Magnesium	7439-95-4			
Manganese (nonfood)	7439-96-5	2.84E+02		2.84E+02
Mercury (elemental)	7439-97-6			
Methoxychlor	72-43-5	1.01E+01		1.01E+01
Methylene chloride (dichloromethane)	75-09-2	1.22E+02	1.01E+01	1.01E+01
2-Methylnaphthalene	91-57-6	4.06E+01		4.06E+01
4-Methyl-2-pentanone (methyl isobutyl ketone)	108-10-1	1.62E+02		1.62E+02

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Table 1.4
Surface Water Screening-Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Surface Water HQ = 0.1 (mg/L)	Carcinogenic Surface Water Risk = 1E-06 (mg/L)	Surface Water Risk = 1E-06 or HQ = 0.1 (mg/L)
2-Methylphenol (o-cresol)	95-48-7	1.01E+02		1.01E+02
4-Methylphenol (p-cresol)	106-44-5	1.01E+01		1.01E+01
Molybdenum	7439-98-7	1.01E+01		1.01E+01
Naphthalene	91-20-3	4.06E+01		4.06E+01
Nickel (soluble)	7440-02-0	4.06E+01		4.06E+01
2-Nitroaniline	88-74-4			
Nitrobenzene	98-95-3	1.01E+00		1.01E+00
4-Nitrophenol	100-02-7	1.62E+01		1.62E+01
n-Nitrosodiphenylamine	86-30-6		1.55E+01	1.55E+01
n-Nitrosodipropylamine	621-64-7		1.08E-02	1.08E-02
Pentachlorophenol	87-86-5	6.08E+01	6.33E-01	6.33E-01
Phenol	108-95-2	1.22E+03		1.22E+03
Pyrene	129-00-0	6.08E+01		6.08E+01
Selenium	7782-49-2	1.01E+01		1.01E+01
Silver	7440-22-4	1.01E+01		1.01E+01
Strontium	7440-24-6	1.22E+03		1.22E+03
Styrene	100-42-5	4.06E+02		4.06E+02
1,1,2,2-Tetrachloroethane	79-34-5	1.22E+02	3.80E-01	3.80E-01
Tetrachloroethene	127-18-4	2.03E+01	1.46E+00	1.46E+00
Tin	7440-31-5	1.22E+03		1.22E+03
Toluene	108-88-3	4.06E+02		4.06E+02
Toxaphene	8001-35-2		6.90E-02	6.90E-02
1,2,4-Trichlorobenzene	120-82-1	2.03E+01		2.03E+01
1,1,1-Trichloroethane	71-55-6	5.68E+02		5.68E+02
1,1,2-Trichloroethane	79-00-5	8.11E+00	1.33E+00	1.33E+00
Trichloroethene	79-01-6	6.08E-01	1.90E-01	1.90E-01
2,4,5-Trichlorophenol	95-95-4	2.03E+02		2.03E+02
2,4,6-Trichlorophenol	88-06-2		6.90E+00	6.90E+00
Uranium (soluble salts)	No CASN	6.08E+00		6.08E+00
Vanadium	7440-62-2	1.42E+01		1.42E+01
Vinyl acetate	108-05-4	2.03E+03		2.03E+03
Vinyl chloride	75-01-4	6.08E+00	1.05E-01	1.05E-01
Xylene (total)	1330-20-7	4.06E+03		4.06E+03
Zinc	7440-66-6	6.08E+02		6.08E+02
Nitrate	14797-55-8	3.24E+03		3.24E+03
Nitrite	14797-65-0	2.03E+02		2.03E+02
Ammonium (as Ammonia)	7664-41-7			
Fluoride (as fluorine)	7782-41-4	1.22E+02		1.22E+02
		pCi/L	**pCi/L**	**pCi/L**
Am-241	14596-10-2			4.08E+02
Pu-239	15117-48-3			3.14E+02
Pu-240	14119-33-6			3.14E+02
U-233	13968-55-3			5.91E+02
U-234	13966-29-5			6.08E+00
U-235	15117-96-1			6.08E+00
U-235+D	15117-96-1(+D)			6.08E+00
U-238	7440-61-1			6.08E+00
U-238+D	7440-61-1(+D)			6.08E+00

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1.3 Subsurface Soil PRGs for the Volatilization Pathway

The WRW subsurface soil exposure scenario associated with volatilization consists of the following pathway: indoor inhalation of volatile organics emanating from subsurface soil for a WRW working at the Site for an average of 18.7 years, spending 50 percent of his or her time indoors. The worker is envisioned spending all of his or her time on the most contaminated areas of the Site. PRGs were calculated for both a 1E-06 risk and an HQ of 0.1. The more conservative of the two values is chosen for the PRG.

1.3.1 PRG Parameters and Equations

Johnson and Ettinger (EPA 2000) introduced a screening-level model that incorporates both convective and diffusive mechanisms for estimating the transport of contaminant vapors emanating from either subsurface soils or groundwater into indoor spaces located directly above the source of contamination. The Johnson and Ettinger model is a one-dimensional analytical solution to convective and diffusive vapor transport into indoor spaces. The model provides an estimated attenuation coefficient that relates the vapor concentration in the indoor space to the vapor concentration at the source of contamination. Inputs to the model include chemical properties of the contaminant, saturated and unsaturated zone soil properties, and structural properties of the building.

The EPA spreadsheets for the Johnson and Ettinger model were used to calculate PRGs associated with volatilization using site-specific and default modeling parameters. The spreadsheets may be downloaded from the EPA Superfund site on the Internet. The user's manual for the model (EPA 2000) provides a discussion of the modeling parameters.

1.3.2 Subsurface Soil Volatilization Screening-Level PRG Values

Table 1.5 presents values for the subsurface soil volatilization screening-level PRGs.

Table 1.5
Subsurface Soil Volatilization Screening-Level PRG Values

		Wildlife Refuge Worker		
Target Analyte	CAS Number	Noncarcinogenic Subsurface Soil HQ = 0.1 Site-specific VF (µg/kg)	Carcinogenic Subsurface Soil Risk = 1E-06 Site-specific VF (µg/kg)	Subsurface Soil Risk = 1E-06 or HQ = 0.1 (µg/kg)
Acenaphthene	83-32-9	1.77E+05		1.77E+05
Acetone	67-64-1	3.10E+05		3.10E+05
Aldrin	309-00-2		2.92E+05	2.92E+05
Aluminum	7429-90-5			
Anthracene	120-12-7			
Antimony	7440-36-0			
Aroclor 1016	12674-11-2			
Aroclor 1221	11104-28-2			
Aroclor 1232	11141-16-5			
Aroclor 1242	53469-21-9			
Aroclor 1248	12672-29-6			
Aroclor 1254	11097-69-1			
Aroclor 1260	11096-82-5			

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Table 1.5
Subsurface Soil Volatilization Screening-Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Subsurface Soil HQ = 0.1 Site-specific VF (µg/kg)	Carcinogenic Subsurface Soil Risk = 1E-06 Site-specific VF (µg/kg)	Subsurface Soil Risk = 1E-06 or HQ = 0.1 (µg/kg)
Arsenic	7440-38-2			
Barium	7440-39-3			
Benzene	71-43-2		1.30E+00	1.30E+00
alpha-BHC	319-84-6		1.14E+04	1.14E+04
beta-BHC	319-85-7			
delta-BHC	319-86-8			
gamma-BHC (Lindane)	58-89-9	3.98E+05	3.82E+04	3.82E+04
Benzo(a)anthracene	56-55-3			
Benzo(a)pyrene	50-32-8			
Benzo(b)fluoranthene	205-99-2			
Benzo(k)fluoranthene	207-08-9			
Benzoic Acid (at pH 7)	65-85-0			
Benzyl Alcohol	100-51-6			
Beryllium	7440-41-7			
bis(2-chloroethyl)ether	111-44-4		6.09E+02	6.09E+02
bis(2-chloroisopropyl)ether	39638-32-9			
bis(2-ethylhexyl)phthalate	117-81-7			
Bromodichloromethane	75-27-4	8.18E+03	2.47E+02	2.47E+02
Bromoform	75-25-2	1.97E+04	4.05E+04	1.97E+04
Bromomethane (methyl bromide)	74-83-9	4.12E+01		4.12E+01
2-Butanone (methyl ethyl ketone)	78-93-3	7.37E+05		7.37E+05
Butylbenzylphthalate	85-68-7			
Cadmium (water)	7440-43-9			
Cadmium (food)	7440-43-9			
Carbon disulfide	75-15-0	2.72E+03		2.72E+03
Carbon tetrachloride	56-23-5		3.05E+01	3.05E+01
alpha-Chlordane	5103-71-9			
beta-Chlordane	5103-74-2			
gamma-Chlordane	12789-03-6			
4-Chloroaniline	106-47-8			
Chlorobenzene	108-90-7	8.57E+03		8.57E+03
Chloroethane (ethyl chloride)	75-00-3	4.31E+04	1.94E+02	1.94E+02
Chloroform	67-66-3		4.71E+01	4.71E+01
Chloromethane (methyl chloride)	74-87-3	3.46E+02	1.44E+02	1.44E+02
2-Chloronaphthalene	91-58-7			
2-Chlorophenol	95-57-8	4.85E+04		4.85E+04
Chromium III	16065-83-1			
Chromium VI	18540-29-9			
Chrysene	218-01-9			
Cobalt	7440-48-4			
Copper	7440-50-8			
Cyanide	57-12-5			
4,4-DDD	72-54-8			

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Table 1.5
Subsurface Soil Volatilization Screening-Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Subsurface Soil HQ = 0.1 Site-specific VF (µg/kg)	Carcinogenic Subsurface Soil Risk = 1E-06 Site-specific VF (µg/kg)	Subsurface Soil Risk = 1E-06 or HQ = 0.1 (µg/kg)
4,4-DDE	72-55-9			
4,4-DDT	50-29-3			
Dibenz(a,h)anthracene	53-70-3			
Dibenzofuran	132-64-9			
Dibromochloromethane	124-48-1	1.69E+04	3.77E+02	3.77E+02
Di-n-butylphthalate	84-74-2			
1,2-Dichlorobenzene (o-)	95-50-1	1.77E+05		1.77E+05
1,4-Dichlorobenzene (p-)	106-46-7			
3,3-Dichlorobenzidine	91-94-1			
1,1-Dichloroethane	75-34-3	8.65E+03		8.65E+03
1,2-Dichloroethane	107-06-2		1.07E+02	1.07E+02
1,1-Dichloroethene	75-35-4	1.05E+03		0.00E+00
1,2-Dichloroethene (total)	540-59-0			
2,4-Dichlorophenol (at pH 6.8)	120-83-2			
1,2-Dichloropropane	78-87-5	8.91E+01	1.85E+02	8.91E+01
cis-1,3-Dichloropropene	10061-01-5	1.71E+02	8.01E+01	8.01E+01
trans-1,3-Dichloropropene	10061-02-6	1.71E+02	8.01E+01	8.01E+01
Dieldrin	60-57-1		2.92E+04	2.92E+04
Diethylphthalate	84-66-2			
2,4-Dimethylphenol	105-67-9			
Dimethylphthalate	131-11-3			
4,6-Dinitro-2-methylphenol (4,6-dinitro-o-cresol)	534-52-1			
2,4-Dinitrophenol	51-28-5			
2,4-Dinitrotoluene	121-14-2			
2,6-Dinitrotoluene	606-20-2			
Di-n-octylphthalate	117-84-0			
Endosulfan I	959-98-8			
Endosulfan II	33213-65-9			
Endosulfan sulfate	1031-07-8			
Endosulfan (technical)	115-29-7			
Endrin (technical)	72-20-8			
Ethylbenzene	100-41-4	1.11E+05	3.79E+03	3.79E+03
Fluoranthene	206-44-0			
Fluorene	86-73-7	1.92E+05		1.92E+05
Heptachlor	76-44-8	1.63E+04	2.68E+02	2.68E+02
Heptachlor epoxide	1024-57-3			
Hexachlorobenzene	118-74-1			
Hexachlorobutadiene	87-68-3	1.40E+05	3.40E+04	3.40E+04
Hexachlorocyclopentadiene	77-47-4	8.12E+03		8.12E+03
Hexachloroethane	67-72-1	1.80E+04	4.81E+04	1.80E+04
Indeno(1,2,3-cd)pyrene	193-39-5			
Iron	7439-89-6			

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Table 1.5
Subsurface Soil Volatilization Screening-Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Subsurface Soil HQ = 0.1 Site-specific VF (µg/kg)	Carcinogenic Subsurface Soil Risk = 1E-06 Site-specific VF (µg/kg)	Subsurface Soil Risk = 1E-06 or HQ = 0.1 (µg/kg)
Isophorone	78-59-1			
Lead	7439-92-1			
Lithium	7439-93-2			
Magnesium	7439-95-4			
Manganese (nonfood)	7439-96-5			
Mercury (elemental)	7439-97-6			
Methoxychlor	72-43-5			
Methylene chloride (dichloromethane)	75-09-2	7.58E+04	2.01E+03	2.01E+03
2-Methylnaphthalene	91-57-6			
4-Methyl-2-pentanone (methyl isobutyl ketone)	108-10-1	3.68E+04		3.68E+04
2-Methylphenol (o-cresol)	95-48-7			
4-Methylphenol (p-cresol)	106-44-5			
Molybdenum	7439-98-7			
Naphthalene	91-20-3	3.67E+04		3.67E+04
Nickel (soluble)	7440-02-0			
2-Nitroaniline	88-74-4			
Nitrobenzene	98-95-3	1.85E+04		1.85E+04
4-Nitrophenol	100-02-7			
n-Nitrosodiphenylamine	86-30-6			
n-Nitrosodipropylamine	621-64-7			
Pentachlorophenol	87-86-5			
Phenol	108-95-2			
Pyrene	129-00-0			
Selenium	7782-49-2			
Silver	7440-22-4			
Strontium	7440-24-6			
Styrene	100-42-5	6.82E+05		6.82E+05
1,1,2,2-Tetrachloroethane	79-34-5	1.60E+05	4.92E+02	4.92E+02
Tetrachloroethene	127-18-4		2.65E+02	2.65E+02
Tin	7440-31-5			
Toluene	108-88-3	2.50E+04		2.50E+04
Toxaphene	8001-35-2			
1,2,4-Trichlorobenzene	120-82-1	9.13E+05		9.13E+05
1,1,1-Trichloroethane	71-55-6	3.19E+04		3.19E+04
1,1,2-Trichloroethane	79-00-5	2.33E+03	3.89E+02	3.89E+02
Trichloroethene	79-01-6	1.44E+03	1.22E+01	1.22E+01
2,4,5-Trichlorophenol	95-95-4			
2,4,6-Trichlorophenol	88-06-2			
Uranium (soluble salts)	No CASN			
Vanadium	7440-62-2			
Vinyl acetate	108-05-4	2.03E+04		2.03E+04
Vinyl chloride	75-01-4	2.39E+02	1.02E+01	1.02E+01

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Table 1.5
Subsurface Soil Volatilization Screening-Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Subsurface Soil HQ = 0.1 Site-specific VF (µg/kg)	Carcinogenic Subsurface Soil Risk = 1E-06 Site-specific VF (µg/kg)	Subsurface Soil Risk = 1E-06 or HQ = 0.1 (µg/kg)
Xylene (total)	1330-20-7			
Zinc	7440-66-6			
Nitrate	14797-55-8			
Nitrite	14797-65-0			
Ammonium (as ammonia)	7664-41-7			
Fluoride (as fluorine)	7782-41-4			

1.4 Groundwater Screening-Level Preliminary Remediation Goal for the Volatilization Pathway

The WRW groundwater exposure scenario associated with volatilization consists of the following pathway: indoor inhalation of volatile organics emanating from groundwater for a WRW working at the Site for an average of 18.7 years, spending 50 percent of his or her time indoors. The worker is envisioned spending all of his or her time on the most contaminated areas of the Site. PRGs were calculated for both a 1E-06 risk and an HQ of 0.1. The more conservative of the two values is chosen for the PRG.

1.4.1 Preliminary Remediation Goal Parameters and Equations

As discussed in Section 1.3.1, Johnson and Ettinger (EPA 2000) introduced a screening-level model that incorporates both convective and diffusive mechanisms for estimating the transport of contaminant vapors emanating from either subsurface soil or groundwater into indoor spaces located directly above the source of contamination. The model is a one-dimensional analytical solution to convective and diffusive vapor transport into indoor spaces. It provides an estimated attenuation coefficient that relates the vapor concentration in the indoor space to the vapor concentration at the source of contamination. Inputs to the model include chemical properties of the contaminant, saturated and unsaturated zone soil properties, and structural properties of the building.

The EPA spreadsheets for the Johnson and Ettinger model were used to calculate PRGs associated with groundwater volatilization using Site-specific and default modeling parameters. The spreadsheets may be downloaded from the EPA Superfund site on the Internet. The user's manual for the model (EPA 2000) provides a discussion of the modeling parameters.

1.4.2 Groundwater Volatilization Screening-Level Preliminary Remediation Goal Values

Table 1.6 presents the values for the groundwater volatilization screening level-PRGs.

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Table 1.6
Groundwater Volatilization Screening-Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Groundwater HQ = 0.1 Site-specific VF (µg/L)	Carcinogenic Groundwater Risk = 1E-06 Site-specific VF (µg/L)	Groundwater Risk = 1E-06 or HQ = 0.1 (µg/L)
Acenaphthene	83-32-9	7.04E+05		7.04E+05
Acetone	67-64-1	2.00E+06		2.00E+06
Aldrin	309-00-2	5.40E+03	3.93E+01	3.93E+01
Aluminum	7429-90-5			
Anthracene	120-12-7			
Antimony	7440-36-0			
Aroclor 1016	12674-11-2			
Aroclor 1221	11104-28-2			
Aroclor 1232	11141-16-5			
Aroclor 1242	53469-21-9			
Aroclor 1248	12672-29-6			
Aroclor 1254	11097-69-1			
Aroclor 1260	11096-82-5			
Arsenic	7440-38-2			
Barium	7440-39-3			
Benzene	71-43-2		3.41E+02	3.41E+02
alpha-BHC	319-84-6		1.30E+03	1.30E+03
beta-BHC	319-85-7			
delta-BHC	319-86-8			
gamma-BHC (Lindane)	58-89-9	5.20E+04	4.99E+03	4.99E+03
Benzo(a)anthracene	56-55-3			
Benzo(a)pyrene	50-32-8			
Benzo(b)fluoranthene	205-99-2			
Benzo(k)fluoranthene	207-08-9			
Benzoic Acid (at pH 7)	65-85-0			
Benzyl Alcohol	100-51-6			
Beryllium	7440-41-7			
bis(2-chloroethyl)ether	111-44-4		2.34E+03	2.34E+03
bis(2-chloroisopropyl)ether	39638-32-9			
bis(2-ethylhexyl)phthalate	117-81-7			
Bromodichloromethane	75-27-4	1.62E+04	4.90E+02	4.90E+02
Bromoform	75-25-2	5.23E+04	2.54E+04	2.54E+04
Bromomethane (methyl bromide)	74-83-9	2.71E+02		2.71E+02
2-Butanone (methyl ethyl ketone)	78-93-3	4.39E+06		4.39E+06
Butylbenzylphthalate	85-68-7			
Cadmium (water)	7440-43-9			
Cadmium (food)	7440-43-9			
Carbon disulfide	75-15-0	1.83E+04		1.83E+04
Carbon tetrachloride	56-23-5		7.77E+01	7.77E+01
alpha-Chlordane	5103-71-9			
beta-Chlordane	5103-74-2			

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Table 1.6
Groundwater Volatilization Screening-Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Groundwater HQ = 0.1 Site-specific VF (µg/L)	Carcinogenic Groundwater Risk = 1E-06 Site-specific VF (µg/L)	Groundwater Risk = 1E-06 or HQ = 0.1 (µg/L)
gamma-Chlordane	12789-03-6			
4-Chloroaniline	106-47-8			
Chlorobenzene	108-90-7	6.64E+03		6.64E+03
Chloroethane (ethyl chloride)	75-00-3	3.94E+05	1.78E+03	1.78E+03
Chloroform	67-66-3		1.46E+02	1.46E+02
Chloromethane (methyl chloride)	74-87-3	4.73E+03	1.97E+03	1.97E+03
2-Chloronaphthalene	91-58-7			
2-Chlorophenol	95-57-8	1.70E+04		1.70E+04
Chromium III	16065-83-1			
Chromium VI	18540-29-9			
Chrysene	218-01-9			
Cobalt	7440-48-4			
Copper	7440-50-8			
Cyanide	57-12-5			
4,4-DDD	72-54-8			
4,4-DDE	72-55-9			
4,4-DDT	50-29-3			
Dibenz(a,h)anthracene	53-70-3			
Dibenzofuran	132-64-9			
Dibromochloromethane	124-48-1	2.88E+04	6.41E+02	6.41E+02
Di-n-butylphthalate	84-74-2			
1,2-Dichlorobenzene (o-)	95-50-1	4.49E+04		4.49E+04
1,4-Dichlorobenzene (p-)	106-46-7			
3,3-Dichlorobenzidine	91-94-1			
1,1-Dichloroethane	75-34-3	3.38E+04		3.38E+04
1,2-Dichloroethane	107-06-2		4.19E+02	4.19E+02
1,1-Dichloroethene	75-35-4	5.57E+03		5.57E+03
1,2-Dichloroethene (total)	540-59-0			
2,4-Dichlorophenol (at pH 6.8)	120-83-2			
1,2-Dichloropropane	78-87-5	5.05E+02	2.44E+02	2.44E+02
cis-1,3-Dichloropropene	10061-01-5	1.43E+03	6.68E-01	6.68E-01
trans-1,3-Dichloropropene	10061-02-6	1.43E+03	6.68E-01	6.68E-01
Dieldrin	60-57-1			
Diethylphthalate	84-66-2			
2,4-Dimethylphenol	105-67-9			
Dimethylphthalate	131-11-3			
4,6-Dinitro-2-methylphenol (4,6-dinitro-o-cresol)	534-52-1			
2,4-Dinitrophenol	51-28-5			
2,4-Dinitrotoluene	121-14-2			
2,6-Dinitrotoluene	606-20-2			

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Table 1.6
Groundwater Volatilization Screening-Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Groundwater HQ = 0.1 Site-specific VF (µg/L)	Carcinogenic Groundwater Risk = 1E-06 Site-specific VF (µg/L)	Groundwater Risk = 1E-06 or HQ = 0.1 (µg/L)
Di-n-octylphthalate	117-84-0			
Endosulfan I	959-98-8			
Endosulfan II	33213-65-9			
Endosulfan sulfate	1031-07-8			
Endosulfan (technical)	115-29-7			
Endrin (technical)	72-20-8			
Ethylbenzene	100-41-4	7.09E+04	2.41E+03	2.41E+03
Fluoranthene	206-44-0			
Fluorene	86-73-7			
Heptachlor	76-44-8	3.80E+01	6.25E-01	6.25E-01
Heptachlor epoxide	1024-57-3			
Hexachlorobenzene	118-74-1			
Hexachlorobutadiene	87-68-3	6.36E+01	1.55E+02	6.36E+01
Hexachlorocyclopentadiene	77-47-4	1.22E+01		1.22E+01
Hexachloroethane	67-72-1	1.41E+03	3.76E+03	1.41E+03
Indeno(1,2,3-cd)pyrene	193-39-5			
Iron	7439-89-6			
Isophorone	78-59-1			
Lead	7439-92-1			
Lithium	7439-93-2			
Magnesium	7439-95-4			
Manganese (nonfood)	7439-96-5			
Mercury (elemental)	7439-97-6			
Methoxychlor	72-43-5			
Methylene chloride (dichloromethane)	75-09-2	3.79E+00	1.00E+04	3.79E+00
2-Methylnaphthalene	91-57-6			
4-Methyl-2-pentanone (methyl isobutyl ketone)	108-10-1	1.71E+05		1.71E+05
2-Methylphenol (o-cresol)	95-48-7			
4-Methylphenol (p-cresol)	106-44-5			
Molybdenum	7439-98-7			
Naphthalene	91-20-3	2.63E+03		2.63E+03
Nickel (soluble)	7440-02-0			
2-Nitroaniline	88-74-4			
Nitrobenzene	98-95-3	3.05E+04		3.05E+04
4-Nitrophenol	100-02-7			
n-Nitrosodiphenylamine	86-30-6			
n-Nitrosodipropylamine	621-64-7			
Pentachlorophenol	87-86-5			
Phenol	108-95-2			

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Table 1.6
Groundwater Volatilization Screening-Level PRG Values

Target Analyte	CAS Number	Wildlife Refuge Worker		
		Noncarcinogenic Groundwater HQ = 0.1 Site-specific VF (µg/L)	Carcinogenic Groundwater Risk = 1E-06 Site-specific VF (µg/L)	Groundwater Risk = 1E-06 or HQ = 0.1 (µg/L)
Pyrene	129-00-0			
Selenium	7782-49-2			
Silver	7440-22-4			
Strontium	7440-24-6			
Styrene	100-42-5	1.50E+05		1.50E+05
1,1,2,2-Tetrachloroethane	79-34-5	2.02E+05	6.19E+02	6.19E+02
Tetrachloroethene	127-18-4		5.44E+02	5.44E+02
Tin	7440-31-5			
Toluene	108-88-3	2.82E+04		2.82E+04
Toxaphene	8001-35-2			
1,2,4-Trichlorobenzene	120-82-1	7.55E+04		7.55E+04
1,1,1-Trichloroethane	71-55-6	8.80E+04		8.80E+04
1,1,2-Trichloroethane	79-00-5	4.93E+03	8.24E+02	8.24E+02
Trichloroethene	79-01-6	1.78E+01	2.09E+03	1.78E+01
2,4,5-Trichlorophenol	95-95-4			
2,4,6-Trichlorophenol	88-06-2			
Uranium (soluble salts)	No CASN			
Vanadium	7440-62-2			
Vinyl acetate	108-05-4	1.11E+05		1.11E+05
Vinyl chloride	75-01-4	2.29E+03	9.75E+01	9.75E+01
Xylene (total)	1330-20-7			
Zinc	7440-66-6			
Nitrate	14797-55-8			
Nitrite	14797-65-0			
Ammonium (as ammonia)	7664-41-7			
Fluoride (as fluorine)	7782-41-4			

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APPENDIX B
Calculation of Ecological Screening Levels, Methods, Sources and Results

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ACRONYMS

BAF	bioaccumulation factor
BDAC	Biota Dose Assessment Committee
CCME	Canadian Council of Ministers of the Environment
CCR	Colorado Code of Regulations
CDPHE	Colorado Department of Public Health and Environment
COC	contaminant of concern
CRA	Comprehensive Risk Assessment
CSM	Conceptual Site Model
DAR	Data Adequacy Report
DOE	U.S. Department of Energy
ECOI	ecological contaminant of interest
ECOPC	ecological contaminant of potential concern
Eco-SSL	ecological soil screening level
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ERA	ecological risk assessment
ESA	Endangered Species Act
ESL	ecological screening level
EU	exposure unit
HQ	hazard quotient
IA	Industrial Area
IHSS	Individual Hazardous Substance Site
kg	kilogram
LOAEL	lowest-observed adverse effects levels
mg/kg	milligrams per kilogram
MIDEQ	Michigan Department of Environmental Quality
MOEE	Ohio Ministry of Environment and Energy
NOAA	National Oceanic and Atmospheric Association
NOAEL	no-observed adverse effects level
ORNL	Oak Ridge National Laboratory

ACRONYMS

PCB	polychlorinated biphenyl
PMJM	Preble's meadow jumping mouse
PRG	preliminary remediation goal
RESRAD	residual radioactive materials computer code
RFCA	Rocky Flats Cleanup Agreement
RFETS or Site	Rocky Flats Environmental Technology Site
RFI/RI	RCRA Facility Investigation/Remedial Investigation
SCM	Site Conceptual Model
SSL	soil screening level
tESL	threshold ecological screening level
TRV	toxicity reference values
USFWS	U.S. Fish and Wildlife Service

1.0 INTRODUCTION

To support the Draft Comprehensive Risk Assessment (CRA), ecological screening levels (ESLs) are developed here for more than 160 ecological contaminants of interest (ECOIs) identified from three main sources: (1) Table 3 of the Rocky Flats Cleanup Agreement (RFCA) Attachment 5 (DOE et al. 1996 [as modified]), (2) contaminants detected at the Site and (3) a list of potentially bioaccumulative analytes from the U.S. Environmental Protection Agency's (EPA's) Toxics Release Inventory Program.

EPA's ecological soil screening level (Eco-SSL) (EPA 2003) process was used as general guidance for developing the soil ESLs or soil screening levels (SSLs) for vertebrate receptors. General equations and procedures from the Eco-SSL guidance were used to calculate SSLs, and extensive use was made of existing databases and compilations of ecotoxicity information. The SSLs were developed consistent with the steps recommended in the guidance as follows:

1. Identify the Wildlife Risk Model: Develop a Site Conceptual Model (SCM) with receptors, exposure pathways, and exposure scenarios. Quantify an equation that relates the contaminant concentration in soil to an acceptable threshold based on an exposure model.

2. Select Surrogate Wildlife Species: Identify species that are representative of the functional groups for which risk is to be evaluated.

3. Estimate Exposure Dose: Determine exposure parameters and quantify dose for each selected contaminant.

4. Derive the toxicity reference values (TRVs): Identify an acceptable dose or exposure.

5. Calculate the Eco-SSL: Calculate the Eco-SSLs by solving the exposure equation for ECOI concentrations in soil that result in exposure equal to the TRV.

2.0 METHODS FOR TASK 1: DEVELOPING A CONCEPTUAL SITE MODEL AND IDENTIFYING RECEPTOR TYPES AND EXPOSURE PARAMETERS

The Rocky Flats Environmental Technology Site (RFETS) environment as it relates to the Ecological Risk Assessment (ERA) is described in detail in the Sitewide Conceptual Model Technical Memorandum prepared for the Draft Watershed ERA (DOE 1996). This model has been updated for the CRA as the SCM and is shown on Figure 7.2 of Section 7 of the CRA Work Plan and Methodology.

2.1 Exposure Models and Receptors of Concern

Primarily, ESLs were calculated based on general toxicological information about the ECOIs, exposure parameters for the selected receptor types, and information on bioaccumulation of specific ECOIs from soil at Rocky Flats. Actual selection of the ESLs and the rationale for their selection is explained in Section 4.0. General methods for calculating ESLs for radionuclide and nonradionuclide ECOIs are presented in the following subsections.

2.1.1 General Exposure Model for Wildlife Soil Screening Levels

The general model for calculating SSLs for nonradionuclide ECOIs estimates the soil concentrations that result in wildlife intake rates (for example, ingestion rate) equal to benchmark values associated with approximate levels of toxicity (or lack thereof). Hereafter, the benchmark values will be referred to as TRVs. The relationship between the estimated environmental exposure and the TRV is usually expressed as a ratio called the "hazard quotient (HQ)" (EPA 1997):

(Equation B-1)

$$HQ = \frac{\text{estimated exposure}}{TRV}$$

Therefore, the SSL is defined as the ECOI concentration in soil that results in an HQ = 1. For wildlife, exposure is estimated based on the following equation that describes the sum of ECOI intake from incidental ingestion of soil and ingestion of forage or prey:

(Equation B-2)

$$Exposure\ (Intake) = \left[(C_{soil} * P_{soil} * FIR * RBA_{soil}) + (\sum_{i=1}^{n} (C_{food} * P_{food} * FIR * RBA_{food}) \right] * AUF$$

Where:

Exposure (Intake) = rate at which an ECOI is ingested from all sources (milligrams per kilogram [mg/kg] body weight/d)

C_{soil}	=	contaminant concentration for contaminant (j) in soil (mg/kg dry weight)
N	=	number of different biota food types in diet,
C_{food}	=	contaminant concentration in food type (i) (mg/kg dry weight)
P_{food}	=	proportion of biota type (i) in diet
FIR	=	food ingestion rate (kilogram [kg] food [dry weight]/ kg BW [wet weight] / d)
RBA_{food}	=	relative bioavailability of contaminant (j) from biota type (i) ($AF_{food} = 1$)
RBA_{soil}	=	relative bioavailability of contaminant (j) from soil ($AF_{soil} = 1$)
TRV	=	toxicity reference value (mg/kg BW/day)
P_{soil}	=	soil ingestion as proportion of diet
AUF	=	area use factor (AUF = 1)

Because the SSL is expressed as an ECOI concentration in soil, the concentration in food must also be expressed as a function of the concentration in soil. To accomplish this,

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bioaccumulation factors (BAFs) that predict the extent to which ECOIs accumulate in forage or prey are used. The BAF can be a simple ratio of ECOI concentration in biota: soil, or may be derived from regression equations if the relationship is nonlinear (EPA 2003). The C_{food} term in the exposure equation can then be replaced:

(Equation B-3)

$$Exposure\,(Intake) = \left[(C_{soil} * P_{soil} * FIR * RBA_{soil}) + (\sum_{i=1}^{n}([BAF * C_{soil}] * P_{food} * FIR * RBA_{food})\right] * AUF$$

To estimate the SSL, the above equation is solved for the C_{soil} that results in an exposure equal to the TRV (that is, HQ = 1). SSLs will be applied for screening both surface and subsurface soil for burrowing receptors.

A much simpler approach was used for aquatic life and nonvertebrate terrestrial receptors. Most toxicological information on aquatic life is already expressed as a concentration in water or bulk sediment concentrations, which can then be used as direct estimates of the ESL.

TRVs used in the above equation were identified from available databases or the scientific literature and are presented in Section 3.1. Data available from RFETS were evaluated to determine whether applicable BAFs can be calculated for site-specific conditions, and used in preliminary remediation goals (PRG) calculations. If not, BAFs from the general scientific literature were identified and reviewed for potential use.

2.1.2 Approach for Radionuclides

Soil benchmarks for radionuclides were developed for RFETS during the Draft Watershed ERA (Higley and Kuperman 1995). Since then, the U.S. Department of Energy's (DOE's) Biological Dose Assessment Committee (BDAC) has developed additional procedures for assessing exposure and risk to terrestrial and aquatic biota using RESRAD-BIOTA computer code (DOE 2003), which became fully available in December 2003. The RESRAD-BIOTA processes were used to verify protectiveness of the Higley and Kuperman benchmarks, and evaluate protectiveness of available surface water and sediment criteria.

Results of the analysis indicated that for some radionuclides, Higley and Kuperman values were higher (less conservative) than those calculated with the RESRAD-BIOTA procedures (Attachment 1). However, it should be noted that for terrestrial animals the radiation exposure limit cited in RESRAD-BIOTA as protective of ecological receptors (1 rad/day) is ten-fold that assumed in Higley and Kuperman (0.1 rad/day). For this analysis, the RESRAD-BIOTA procedures were adjusted to use 0.1 rad/day for comparison to the Higley and Kuperman values. If the default RESRAD-BIOTA values had been used, benchmarks would have been 10-fold higher (that is, less conservative). (Note that the limits for aquatic animals are the same [0.1 rad/day] [Attachment 1].)

The analysis also shows that values developed for ecological receptors using either approach were considerably higher than values adopted for managing radionuclide risks to human receptors at the Site. In most cases, soil criteria were two to three orders of magnitude larger. Therefore, if the Site is managed to protect human health and exposure point concentration are calculated using similar methods, then ecological receptors will be protected. This applies to special status species (for example, threatened or endangered) and nonthreatened or endangered receptor groups.

An exception to the above is exposure to subsurface soil and surface water. For the human health assessment in the Industrial Area (IA), the pathway to subsurface soil will not be evaluated because institutional controls prevent disturbance of soil. For surface water, ecological benchmarks are lower than human health values for some radionuclides, primarily due to the higher use rate assumed in the calculations. For these two pathways, RESRAD-BIOTA were used to calculate ESLs.

2.1.3 Identification of Representative Receptors

The purpose of the ESLs is to provide a mechanism for evaluating ecotoxicological risks from potentially contaminated abiotic media by comparing data on ECOI concentrations to benchmark values representing potential thresholds of adverse effects. Ecological receptors and their forage or prey utilize soil, sediment, and surface water with widely varying rates and intensities. Generally, species or functional groups that have the most extensive contact with soil or sediment, and/or the smallest home ranges, have the highest potential exposure. Assuming similar sensitivities to toxic effects of ECOIs, ESLs developed for such species are generally protective of groups with lower contact rates (EPA 2003). Therefore, ESLs were developed for the potentially most-exposed functional groups present at RFETS:

- Fossorial (burrowing) small mammals (herbivores and omnivores);
- Small ground-feeding birds;
- Large mammalian herbivores;
- Mammalian predators; and
- Avian predators.

The SCM (DOE 1996) and more recent surveys identify several species of fossorial mammals as present at RFETS, including the deer mouse (*Peromyscus maniculatus*), meadow vole (*Microtus pennsylvanicus*), prairie vole (*M. ochrogaster*), plains harvest mouse (*Reithrodontomys montanus*), black-tailed prairie dog (*Cynomys ludavicianus*), and Preble's meadow jumping mouse (PMJM) (*Zapus hudsonius preblei*). Each of these species constructs and/or occupies borrows for significant parts of their life histories.

The black-tailed prairie dog and the PMJM are species of particular concern in Colorado. The prairie dog is the subject of voluntary habitat conservation initiatives in Colorado and adjoining states aimed at preventing the need for listing under the Endangered Species Act (ESA). The PMJM is a relatively rare subspecies found only along the Front Range of the Rocky Mountains. The species was listed as "threatened" by the U.S. Fish and Wildlife

Service (USFWS) in May 1998. Both species are known to occur at RFETS and, although these species represent essentially the same functional group (herbivorous burrowing small mammals), they are listed here because of their special legal and/or policy status. A generalized small mammal (for example, deer mouse) was also evaluated as a representative receptor. The deer mouse was evaluated using two models and varying only the assumed diet (herbivorous versus omnivorous).

The risk to small ground-feeding birds was not previously assessed in the Watershed ERA. Several candidate species known from RFETS (DOE 1995) include dark-eyed junco (*Junco hyemalis*), black-headed grosbeak (*Pheucticus melanochephalus*), lazuli bunting (*Passerina amoena*), spotted and green-sided towhees (*Pipilo chlorurua* and *P. erythrophthalmus*), mourning dove (*Zenaida macroura*), and house finch (*Carpodacus mexicanus*). The mourning dove was used by EPA in developing Eco-SSLs and was selected to represent ground-feeding birds due to the abundance of available information necessary to estimate intake and therefore risk.

In addition to the above receptor groups, ESLs were developed for the American kestrel (*Falco sparverius*), an avian predator, and coyote (*Canis latrans*), a mammalian predator. The kestrel is a small falcon that is abundant in the region around RFETS. It does not have intimate contact with the soil, but represents an upper-level consumer that could be exposed to contaminants that accumulate in prey species. The coyote represents the upper-level mammalian consumer that could also be exposed to ECOIs at the Site.

In the upland areas of the Site, terrestrial invertebrates and plants will be evaluated as receptors. In the drainages, the general aquatic community will also be evaluated as a receptor. Because no species-specific toxicity information is generally available for any of these three receptors, the entire community of species that make up the population of each receptor group at RFETS will be evaluated as a whole.

Receptor-specific parameters necessary to implement the exposure estimation described in Section 3.1 are listed in Table B.1. When ESLs are used to evaluate an exposure unit (EU) that consists of only one home range, it is necessary that the ESL accounts for the behavior-based variability in exposure. That is, the ESL is calculated from the dose-based TRV using one or more exposure assumptions that are "high-end," rather than all "average" exposure values. This ensures that when the ESL is applied to the mean concentration in an exposure area, it estimates the risk to a high-end receptor rather than just an average receptor. This is appropriate for the large, wide-ranging receptors given that they will be evaluated on a Sitewide basis in the CRA.

When ESLs are applied to an exposure area that includes many home ranges (that is,for the receptors with limited home ranges), the result is a distribution of HQ values across the EU that characterizes the variation due to differences in concentrations across several home ranges. In this situation, the ESL calculation is based on an individual with average (rather than high-end) exposure parameters, because the variation in mean concentration between home ranges is typically large compared to the variation in exposures within a home range due to differences in behavior.

3.0 METHODS FOR TASK 2: IDENTIFYING AND SELECTING TOXICITY REFERENCE VALUES AND BIOACCUMULATION FACTORS FOR VERTEBRATE SOIL SCREENING LEVEL CALCULATION

This section provides the procedures followed to select TRVs and BAFs that are used for calculation of SSL values.

3.1 Derivation of Toxicity Reference Values for Vertebrate Receptors:

As noted in Section 2.0, EPA's Eco-SSL (EPA 2003) process was generally followed to identify the more relevant TRVs for representative species types. Figure B.1 presents a graphical view of the TRV selection process for vertebrate receptors.

3.1.1 Previously Published Toxicity Reference Values

The major sources of toxicity information for deriving TRVs are publicly available databases of TRVs and no-observed adverse effects level/lowest-observed adverse effects level (NOAEL/LOAEL) presented in peer reviewed literature sources. This information was obtained, as available, for the ECOIs listed in Table B.2. The three sources were determined to have adequate data quality to be used in the RFETS ESL calculations. Therefore, TRVs presented in these sources were used unedited from the original source regardless of manipulations of study information by the authors. If both a NOAEL and LOAEL TRV are identified, a threshold value that represents the geometric mean between the two values is presented in order to calculate a threshold-level ESL (tESL) if the data are of sufficient quality to calculate a tESL (Appendix B, Section 3.1.4).

As discussed earlier, ECOIs were identified using the list of contaminants of concern (COCs) presented for surface soil contained in Table 3 of RFCA Attachment 5 (DOE et al. 1996). In addition, the entire database of chemical data was analyzed to determine the presence of ECOIs that were not included in the RFCA table. This analysis will be documented in its entirety in the CRA Data Adequacy Report (draft scheduled for May 2004) and resulted in the addition of at least nine new ECOIs to the RFCA Table 3 list. Additions and/or deletions to this list may occur as characterization data are developed for the Site. Additions of chemicals will require a literature search and ESL calculation for each added ECOI. Based on the framework presented here, development of added ECOIs can be greatly expedited to help ensure availability for use in the assessment process.

The following hierarchy of resources were searched for toxicological information to provide previously published TRVs:

1. EPA's guidance for developing Eco-SSLs (EPA 2003);

2. TRVs developed for U.S. Navy facilities in California (PRC 1998); and

3. Benchmarks developed for the Oak Ridge National Laboratory (ORNL) (Sample et al. 1996).

3.1.2 Literature Review of Toxicity Data

The sources presented in the previous section provided TRVs for a limited list of ECOIs. It was necessary to perform a more detailed search for toxicity information for the remaining list of ECOIs. A database of TRVs identified from literature sources was compiled. The available TRVs for the Site soil-associated ECOIs are based on the following criteria:

- Oral exposure studies only from which a dose was calculable;
- Reproductive and developmental endpoints for acute exposure during discrete, critical lifestage, as well as subchronic or chronic, if available; and
- Growth and mortality endpoints. As per the Eco-SSL guidance, these are used as upper-bound TRVs in case reproduction/developmental TRVs are higher than longer-term exposure survival endpoints.

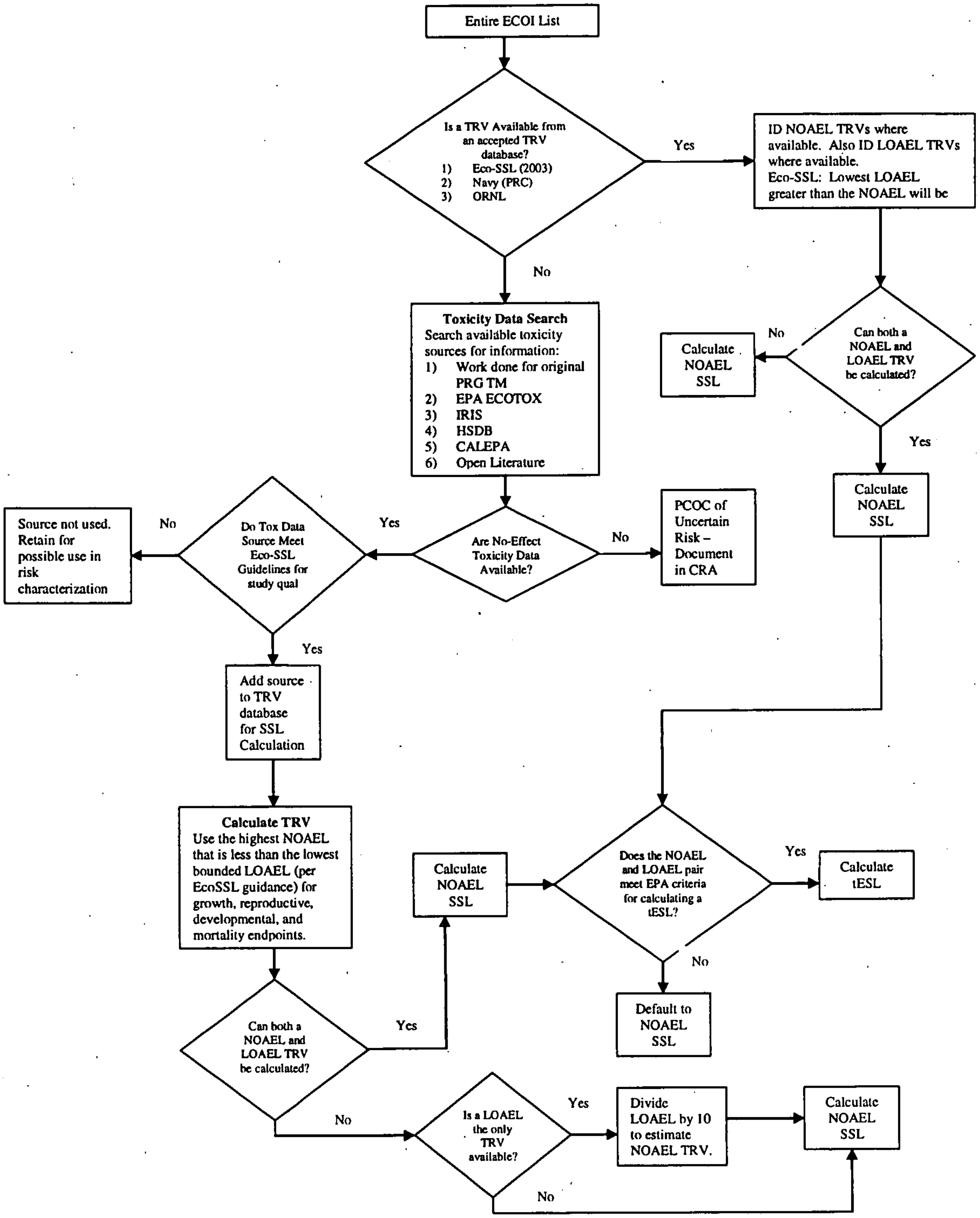
Each of the sources of TRVs were then evaluated for data quality using the EPA (2003) Eco-SSLs 10-step scoring system that is described in detail in Attachment 4-4 of EPA (2003). If the TRV sources score high enough, they were included in the TRV calculation.

Where sufficient data are available (that is, greater than two studies that meet acceptable criteria), TRVs were calculated by obtaining the highest NOAEL that is lower than the lowest bounded LOAEL, for the applicable endpoints. A comprehensive NOAEL TRV was calculated for each ECOI using a compilation of all acceptable sublethal endpoints available from the literature search database. For those ECOIs that lack sufficient toxicological data to reliably calculate mean nonlethal TRVs, it was decided whether to adopt TRVs using other methods such as a critical study or to consider the ECOI to have inadequate toxicity data. The ECOIs that have inadequate toxicity data from which to calculate a TRV will be discussed qualitatively in the CRA Report.

3.1.3 Ecological Contaminants of Interest with Insufficient Data

For some ECOIs, both a NOAEL and a LOAEL TRV are not available for both mammalian and avian receptors. Where only a LOAEL TRV was available, the NOAEL was estimated by dividing the LOAEL TRV by 10. No estimates of a missing LOAEL value were made. In addition, no interclass extrapolations were used to estimate avian TRVs from mammalian endpoints. No SSLs were calculated when no class-specific data were available for the ECOI; these will be noted and discussed in the uncertainty section of the CRA. The use of surrogate chemicals to evaluate ECOI toxicity was reviewed on a case-by-case basis.

Figure B.1 – TRV Identification Process for Vertebrate SSLs



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3.1.4 Calculation of Threshold Toxicity Reference Values

The ecological contaminant of potential concern (ECOPC) identification process in the CRA Methodology specifies that if the toxicity data for a particular ECOI are of sufficient quality, a tESL was calculated. Ideally, the TRV used is the threshold dose at which the response in a group of exposed organisms first begins to be significantly greater than in unexposed receptors. The threshold dose is seldom known, but is bounded between two experimental values:

- NOAEL = Highest administered dose that did not cause an effect; and
- LOAEL = Lowest administered dose that did cause an effect.

If the NOAEL and LOAEL are both fairly close to the threshold, then the geometric mean of the two values is likely to be a reasonable estimate of the true threshold dose. However, if neither the NOAEL and/or the LOAEL is close to the threshold, then the geometric mean may not be a reliable estimate of the threshold. Several different cases may be distinguished, as shown below:

NOAEL	LOAEL	Estimated Threshold
Close	Close	Reliable
Too low	Close	Underestimate
Close	Too high	Overestimate
Too low	Too High	Unknown (unreliable)

Because of the potential error that might occur in an estimate of the threshold when neither the NOAEL and/or the LOAEL is close to the true threshold, a set of data quality rules is needed in order to judge whether the NOAEL/LOAEL data are sufficient to allow the derivation of a reliable estimate of the threshold. The data quality rule is as follows:

A threshold was only calculated if the LOAEL represents a response that is at the low end of the dose response curve (for example, LOAEL < the 20 percent effects concentration [EC20]).

There is no requirement regarding the value of the NOAEL.

This approach minimizes the hazard that the threshold will be significantly too high by limiting the type of LOAEL that is acceptable. It is recognized that by accepting cases where the NOAEL is far below the LOAEL, the chances are increased the threshold will be far too low, but this error is conservative (protective) and may still be preferable to using the NOAEL alone.

3.2 Bioaccumulation Factor Selection or Calculation for Vertebrate Receptor Ecological Screening Levels

As discussed in Section 2.0, BAFs were identified and calculated for use in the ESL development process. The procedures used in this process closely correspond to those developed in the Eco-SSL guidance (EPA 2003). Consistent with the Eco-SSL guidance, BAFs are simple ratios of ECOI concentrations between biota and soil, or are based on quantitative relationships such as linear, logarithmic, or exponential equations.

BAFs were calculated or identified for the following pathways:

- Soil-to-plant;
- Soil-to terrestrial invertebrates; and
- Soil-to-small mammals or birds.

3.2.1 Bioaccumulation Factor Information Sources

Specific sources used to obtain and calculate the BAFs presented in Table B.3 include EPA (2003), ORNL (1998), Sample et al. (1998a, 1998b), and EPA (1999a).

3.3 Identification of Sediment Ecological Screening Levels

For sediment-based aquatic life criteria, modeling of uptake from sediment into prey tissues is not generally necessary. In general, most sediment quality TRVs are presented as simple bulk concentrations protective of benthic species. These benchmarks are typically derived by allowing a test species to be exposed to bulk sediments of known contaminant concentrations for a prescribed period of time. The effects-based benchmark can then be compared to a sediment concentration in order to assess the potential for risk to sediment-dwelling aquatic species.

A variety of published sources for benchmarks were reviewed for use as ESLs. Prior to beginning the task of identifying sediment benchmarks, the RFETS sediment database was queried to determine which ECOIs discussed in the soil ESL process were detected in sediments at RFETS. For those ECOIs that were detected at least once in sediments, two sediment ESLs were identified from the scientific and regulatory literature. One ESL was identified that represents concentrations below which no adverse effects are expected. A second ESL was identified which represents the concentrations at which some adverse effects are expected.

Sediment ESLs were identified from the following sources: CCME (1999), NOAA (1999), Long et al. (1995), and MacDonald et al. (1999, 2000a, 2000b).

3.4 Identification of Surface Water Ecological Screening Levels

Similar to the sediment ESLs discussed above, surface water ESLs were identified from several published databases of surface water quality criteria. These concentrations represent the potential for toxic effects to the aquatic community. Two ESLs were identified, where possible, for each ECOI detected in a surface water or groundwater sample at RFETS. An acute and chronic ESL was identified from the following sources: Colorado Department of Public Health and Environment (CDPHE) Regulation Number 31 (5 Colorado Code of Regulations [CCR] 1002-31), EPA (1999b, 2002), MIDEQ (2003), CCME (2002), Suter and Tsao (1996), and NY State (1998).

3.5 Identification of Soil Screening Levels for Soil Invertebrates

SSLs were identified for soil invertebrates. As with surface water and sediments these SSLs are represented by concentration in soil below which no effects are expected. A relatively large database of soil invertebrate SSLs is available for earthworm toxicity. This, however, is highly conservative because earthworms are generally more susceptible to contamination than other invertebrates due to their intimate contact with soil that includes ingestion and constant burrowing. Earthworms also have a thin epidermis that provides little protection from contaminants in soil.

Where possible, soil invertebrate SSLs were identified for more appropriate nonearthworm receptors such as the cricket. However, given the scarcity of nonearthworm SSLs, earthworm SSLs were used when no other sources existed. In addition, the values presented in the Ontario Ministry of Environment and Energy guidance (MOEE 1996) represent benchmarks considered to be protective of both plant and invertebrate receptors. Both receptor types will be screened against these benchmarks and the uncertainties associated with this type of multireceptor benchmark will be discussed. The MOEE (1996) benchmarks were only used when no other applicable value is available. The following sources were used to identify SSLs for soil invertebrates: EPA (2003), Efroymson et al. (1997a), and MOEE (1996).

3.6 Identification of Soil Screening Levels for Terrestrial Plants

SSLs that can be used to predict the potential for effects to terrestrial plant communities were also identified for the entire list of soil ECOIs. Terrestrial plant SSLs are typically concentrations of ECOIs in soil that below which are not expected to have adverse effects to the plant community. As discussed above, the values presented in MOEE (1996) represent benchmarks considered to be protective of both plant and invertebrate receptors. Both receptor types will be screened against these benchmarks and the uncertainties associated with this type of multireceptor benchmark will be discussed. The MOEE (1996) benchmarks will only be used where no other applicable vegetation benchmark is available. Terrestrial plant SSLs were identified from the following sources: EPA (2003), Efroymson et al. (1997b), CCME (1999), and MOEE (1996).

4.0 ECOLOGICL SCREENING LEVELS

The ESLs represent generic concentrations below which little to no risk is predicted to populations of receptors potentially inhabiting RFETS. Tables B.4 through B.? present the ESLs for the receptors presented in Table B.1. Benchmark ESL values for aquatic life in sediment and surface water are presented in Tables B.4 and B.5 and benchmark SSLs for terrestrial invertebrates and plants are presented in Table B.6. Vertebrate SSLs are presented in Tables B.7 through B.? Table B.? presents the radionuclide SSLs.

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Table B.1 Exposure Factors for Ecological Screening Levels

			Percentage of Diet							
Receptor	**Body Weight (kg)**	**Body Weight Reference**	**Plant Tissue**	**Invertebrate Tissue**	**Bird or Mammal Tissue**	**Dietary Reference**	**IR food (kg/kg BW day^{-1})**	**Ingestion Rate Reference**	**Percentage of Diet as Soil**	**Soil Ingestion Reference**
Vertebrate Receptors										
PMJM	0.019	Morrison and Ryser (1962)	0.7	0.3	0	Estimated from Whitacker (1972)	0.17	USEPA (1993) - Estimated- Nagy (1987)	2.4	Beyer et al. (1994) - Meadow Vole used as surrogate
Deer Mouse - Insectivore	0.0187	Flake (1973)	0	1	0	Generalized Diet	0.065	Cronin and Bradley (1988)	2	Beyer et al. (1994)
Deer Mouse - Herbivore	0.0187	Flake (1973)	1	0	0	Generalized Diet	0.111	Cronin and Bradley (1988)	2	Beyer et al. (1994)
Prairie Dog	1.14	University of Michigan (2004) - Online	1	0	0	Generalized Diet	0.029	USEPA (1993) - Estimated- Nagy (1987)	7.7	Beyer et al. (1994)
Coyote - Generalist	12.75	Bekoff (1977) - Average of male and female weights	0	0.25	0.75	Generalized Diet	0.015	Gier (1975)	4	Beyer et al. (1994) - High end estimate
Coyote - Insectivore	12.75	Bekoff (1977) - Average of male and female weights	0	1	0	Generalized Diet	0.015	Gier (1975)	2	Beyer et al. (1994)
Coyote - Carnivore	12.75	Bekoff (1977) - Average of male and female weights	0	0	1	Generalized Diet	0.015	Gier (1975)	2	Beyer et al. (1994)

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Receptor	Body Weight (kg)	Body Weight Reference	Percentage of Diet: Plant Tissue	Percentage of Diet: Invertebrate Tissue	Percentage of Diet: Bird or Mammal Tissue	Dietary Reference	IR food (kg/kg BW day⁻¹)	Ingestion Rate Reference	Percentage of Diet as Soil	Soil Ingestion Reference
Vertebrate Receptors										
Mule Deer	67	Anderson et al. (1974) - Average of male and female weights.	1	0	0	Kufeld et al. (1973)	0.022	Aldredge et al. (1974)	1.7	Beyer et al. (1994) - High end estimate
Mourning Dove	0.113	Average of adult values from CalEPA (2004) Online Database	1	0	0	Cowan (1952)	0.23	USEPA (2003)	9.3	Beyer et al (1994) - Wild turkey used as a surrogate.
American Kestrel	0.116	Brown and Amadon (1968); Average value	0	0.2	0.8	Generalized Diet from several studies presented in the Watershed ERA (DOE, 1996)	0.092	Kolpin et al. (1980)	5	Estimated Value based on conservative estimates
Non-Wildlife Terrestrial Receptors										
Terrestrial Invertebrates	NA									
Terrestrial Plants	NA									
Aquatic Life										
Sediment Dwelling Aquatic Macroinvertebrates	NA									
General Aquatic Life	NA									

NOTE: Receptor parameters for all receptors with the expection of the Prairie Dog and the Mourning Dove were taken from the Watershed Risk Assessment (DOE, 1996).

All exposure factors are estimates of central tendency except where noted.

All values are presented in a dry weight basis.

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APPENDIX B
Attachment I

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G
consulting
scientists and
engineers

MEMORANDUM

MFG PROJECT: 010056

TO: **Mark Lewis**

CC: **Jan Johnson, Ph.D.**
Bob Meyer, Ph.D.

FROM: **Craig Little**

DATE: **10/21/2003**

SUBJECT: **Examination of Radiological Benchmarks for Rocky Flats**

I was tasked to examine existing radiological benchmarks for wildlife at the Rocky Flats Environmental Technology Site (RFETS). Specifically, I reviewed the apparently unpublished report by Higley and Kuperman (1995) and was requested to express an opinion about whether or not the concentrations in that report were protective and/or overly conservative in light of the DOE's Standard (DOE-STD-1153-2002) "A Graded Approach for Evaluating Radiation Doses To Aquatic and Terrestrial Biota" (DOE, 2002). This memo summarizes those findings.

The DOE Standard's graded approach can be used to address requirements for radiological protection of the environment contained in DOE Orders. The Standard can be downloaded from the Biota Dose Assessment Committee website: http://homer.ornl.gov/oepa/public/bdac. Biota Concentration Guides were derived for twenty-three radionuclides. Accompanying the standard is the RAD-BCG calculator, a spreadsheet precursor to the more detailed RESRAD-BIOTA model that became available earlier this month. The standard addresses use of the RAD-BCG calculator RESRAD-BIOTA was designed to be consistent with the graded approach and the standard's biota concentration guidelines (BCGs). RESRAD-BIOTA may also be downloaded from the BDAC website. The user's manual for RESRAD-BIOTA is not yet available, but should be published in December, 2003 or January, 2004.

As stated by Clarke and Holm (2003), "...there are no internationally agreed criteria or policies that explicitly address protection of the environment from ionising radiation, although many international agreements and statutes call for protection against pollution

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generally." While this remains true, some standards for protection of biota do exist as summarized below. Further, it is important to note a major difference between radiation protection of humans and non-humans. Standards to protect humans are pointed toward protection of the individual members of the public or workers from exposures to either chronic or acute exposures. Consideration of "safe" levels of radiation exposure to non-humans is geared towards protection of the population as opposed to individual members of the population.

While it is not the intent of this memo to explore the accuracy of the limiting concentrations, several observations may be made. Higley and Kuperman (1995) considered both external and internal dose when arriving at a benchmark value. Although not explicitly stated, Higley and Kuperman (1995) consider all modes of intake into the organism by use of a concentration ratio. A concentration ratio for small mammals may be expressed as the concentration in the mammal tissues divided by the concentration in the soil. Entry into the animal may be by inhalation of dust, ingestion of soil or ingestion of contaminated food stuffs. The resulting concentration ratio would essentially integrate potential dose from all pathways involving soil.

For internal doses, Higley and Kuperman assumed a limiting dose of 100 mrad/d and by knowing the effective energy absorbed in tissue by each radionuclide, calculated a limiting tissue concentration. Using cited values of concentration ratios and assuming first order kinetics, they calculated the limiting concentration in the medium of choice. We did not attempt to reproduce their calculations. Because the user's manual for RESRAD-BIOTA is not yet available, it is unclear how internal doses were generated in that code. Hence, the limiting concentrations given by the respective documents were taken at face value.

Higley and Kuperman refer to a safe exposure level as a "no observable adverse effect level," (NOAEL), which they take to be 0.1 rad/d (Table 1) for either aquatic or terrestrial animal populations. They did not consider plant populations. In comparison, DOE Standard 1153-2002 (DOE, 2002) and DOE Order 5400.5 specify a limit of 1 rad/d for aquatic animals, which agrees with the level mentioned in NCRP (1991). DOE Standard 1153-2002 also suggests a protective level of 1 rad/d for terrestrial plants, but for terrestrial animals a level of 100 mrad/day is specified (Table 1). The recently released assessment code, RESRAD-BIOTA (DOE, 2003) defaults to the DOE protection levels listed in Table 1, but the user may override defaults during the Level 1 screening process. (The User's Manual for RESRAD-BIOTA is not yet available, so all assumptions implicit in use of the model may not be obvious.)

Table 1. Protective Dose Levels for Biota

	Chronic absorbed dose, rad/d	
Organism	Higley and Kuperman (1995)	DOE (2002)
Aquatic animals	0.1	1.0
Terrestrial plants	N/A	1.0
Terrestrial animals	0.1	0.1

Higley and Kuperman (1995) identified fourteen contaminants as presenting potential ecological risk at RFETS: ^{3}H, ^{89}Sr, ^{90}Sr, ^{137}Cs, ^{226}Ra, ^{228}Ra, $^{233/234}$U, ^{235}U, ^{238}U, ^{238}Pu, ^{239}Pu, and ^{241}Am, gross α, and gross β.
Only the isotopic contaminants were specifically considered in the 1995 document. Higley and Kuperman developed a series of site-specific benchmarks for radionuclides in soils, water and sediment using a combination of site-specific data or limiting values derived from the concentration ratios or a kinetic approach. These are summarized in Tables 2-4. Neither Pu-238 nor Sr-89 is considered by RESRAD-BIOTA. It is important to note that these limiting concentrations are for single radionuclides, not a mix of radionuclides. If multiple radionuclides are present then a weighted average, similar to a hazard index, is calculated and no single nuclide could approach its limiting concentration.

For purposes of this comparison, a single medium was considered each time and RESRAD-BIOTA's Level 1 screening mode was used. When used in Level 1 mode, RESRAD-BIOTA simply compares input data to the Biota Concentration Guideline (BCG) and calculates the ratio. As suggested in the previous paragraph, a sum of the ratios of the input concentration to the BCG is calculated. If the sum exceeds unity, then the user is prompted to perform more detailed analyses that involve use of actual data, better defined exposure areas, etc.

The values listed in Tables 2-4 are for a single contaminated medium, not multiple media. In that respect, these values may not be realistic. It is not uncommon for contaminated soil to erode into and contaminate a water supply and its associated sediment. However, to allow a direct comparison to Higley and Kuperman only single media were considered.

As shown in Table 2, dose to the terrestrial animal limits the concentration in soil. Of the radionuclides listed, the ratio of limiting concentrations from Higley and Kuperman vs. RESRAD-BIOTA range from approximately 8% for Ra-228 to 5.3 for Sr-90. The average Higley and Kuperman/RESRAD-BIOTA ratio is 1.55, which means that for the listed radionuclides, RESRAD-BIOTA is somewhat more conservative. However, for Pu-239, Ra-226, Ra-228, U-233/234, and U-235, the limiting concentration in soils listed by Higley and Kuperman is lower than (more conservative than) the value used in RESRAD-BIOTA. The difference is most extreme for Ra-228, which RESRAD-BIOTA allows to a concentration of 43.9 pCi/g, but Higley & Kuperman limit to 3.5 pCi/g. These ratios are illustrated in Fig. 1.

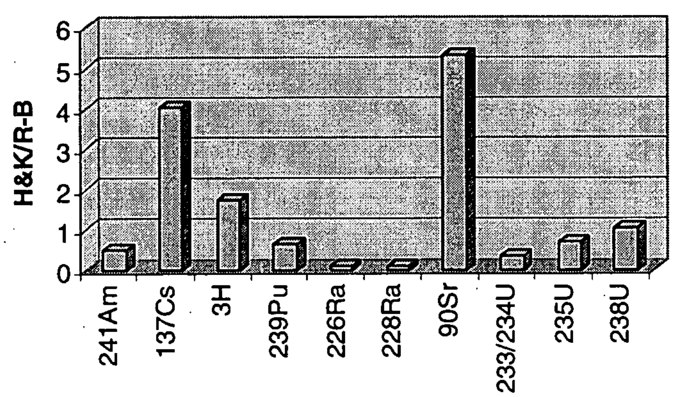
Neglecting Ra-228, the mean of the remaining ratios increases to 1.74. The most common radionuclide at RFETS, Pu-239 is limited to 3800 pCi/g by Higley and Kuperman while RESRAD-BIOTA has a limiting concentration of 6110 pCi/g. Likewise, for the uranium isotopes RESRAD-BIOTA tends to have higher soil limiting concentrations. The exception is U-238, for which the limiting concentrations are essentially equivalent.

Table 2. Concentrations of Radionuclides in Soil to Limit Absorbed Dose to 100 mrad/d to a Terrestrial Species.

	(pCi/g)			
Contaminants of Concern	Higley and Kuperman (1995)	RESRAD-BIOTA BCG (2003)	Higley & Kuperman / RESRAD-BIOTA	Limiting Organism
^{241}Am	1.90E+03	3.89E+03	4.88E-01	Terrestrial animal
^{137}Cs	8.40E+01	2.08E+01	4.04E+00	Terrestrial animal
^{3}H	3.00E+05	1.74E+05	1.72E+00	Terrestrial animal
^{238}Pu	3.50E+03			Terrestrial animal
^{239}Pu	3.80E+03	6.11E+03	6.22E-01	Terrestrial animal
^{226}Ra	5.40E+00	5.06E+01	1.07E-01	Terrestrial animal
^{228}Ra	3.50E+00	4.39E+01	7.97E-02	Terrestrial animal
^{89}Sr	2.30E+02			Terrestrial animal
^{90}Sr	1.20E+02	2.25E+01	5.33E+00	Terrestrial animal
$^{233/234}$U	1.80E+03	4.98E+03	3.61E-01	Terrestrial animal
^{235}U	1.90E+03	2.77E+03	6.86E-01	Terrestrial animal
^{238}U	1.60E+03	1.58E+03	1.01E+00	Terrestrial animal

* RESRAD-BIOTA deals with these separately; for comparison purposes, the BCG of the two were averaged.

Fig. 1. Ratio of Limiting Concentrations in Soil.



As mentioned above, contaminated water is often accompanied by contaminated sediment, but in the case of the data in Table 3, the assumption is made that contaminated water has not contaminated the sediment and the dose delivered to the animals was from exposure to the water alone. Modeling of sediment contamination by RESRAD-BIOTA is accomplished either by using a default k_d that calculates sediment concentration by modifying input water concentration or by inputting a specific sediment concentration. For purposes of this comparison, zero concentrations were used for sediment. Depending on the radionuclide, the limiting organism is either an aquatic animal or a riparian animal.

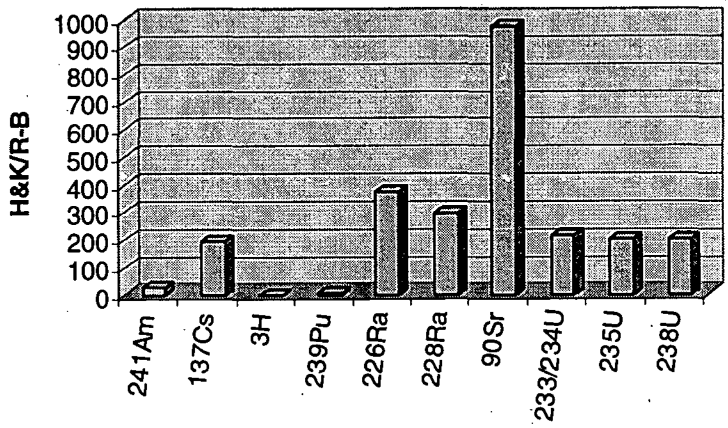
Table 3. Concentrations of Radionuclides in Water to Limit Absorbed Dose to 100 mrad/d to an Aquatic Species

	(pCi/L)			
Contaminants of Concern	Higley and Kuperman (1995)	RESRAD-BIOTA BCG (2003)	Higley & Kuperman / RESRAD-BIOTA	Limiting Organism
Americium-241	1.30E+03	4.38E+01	2.97E+01	Aquatic Animal
Cesium-137	8.20E+03	4.26E+01	1.92E+02	Riparian Animal
Hydrogen-3	1.90E+08	2.65E+08	7.17E-01	Riparian Animal
Plutonium-238	9.20E+01			
Plutonium-239	1.00E+02	1.87E+01	5.35E+00	Aquatic Animal
Radium-226	3.80E+02	1.02E+00	3.73E+02	Aquatic Animal
Radium-228	2.50E+02	8.49E-01	2.94E+02	Aquatic Animal
Strontium-89	7.00E+05			
Strontium-90	2.70E+05	2.78E+02	9.71E+02	Riparian Animal
Uranium-233/234	4.30E+03	2.01E+01	2.14E+02	Aquatic Animal
Uranium-235	4.30E+03	2.17E+01	1.98E+02	Aquatic Animal
Uranium-238	4.40E+03	2.23E+01	1.97E+02	Aquatic Animal

* RESRAD-BIOTA deals with these separately; for comparison purposes, the BCG of the two were averaged.

The average ratio of Higley and Kuperman to RESRAD-BIOTA is approximately 250, which means that for these radioactive materials in water, Higley and Kuperman tend to allow higher concentrations than RESRAD-BIOTA. The only exception is tritium for which Higley and Kuperman allow 72% of the RESRAD-BIOTA limiting concentration. For the actinides Am-241 and Pu-239, Higley and Kuperman allow approximately 30 and 5 times higher concentrations than RESRAD-BIOTA. These ratios are illustrated in Fig. 2.

Fig. 2. Ratio of Limiting Concentrations in Water.



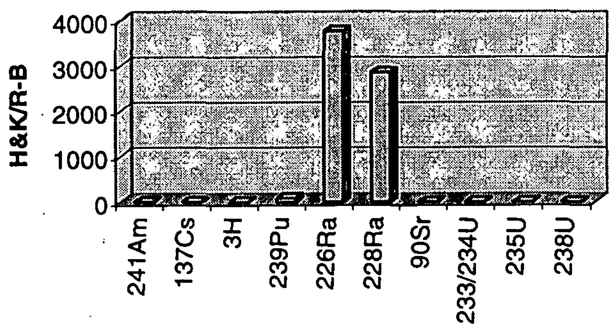
Contaminated water is often accompanied by contaminated sediment, but in the case of the data in Table 4, the assumption is made that the sediment is contaminated while the water is not. Modeling of sediment contamination by RESRAD-BIOTA is accomplished either by using a default k_d that calculates sediment concentration by modifying input water concentration or by inputting a specific sediment concentration. For purposes of this comparison, zero concentrations were used for water and sediment concentrations were manually entered. For radioactive materials in sediments, the limiting organism was the riparian animal.

Table 4. Concentrations of Radionuclides in Sediment to Limit Absorbed Dose to 100 mrad/d to an Aquatic Species

	(pCi/g)			
Contaminants of Concern	**Higley and Kuperman (1995)**	**RESRAD-BIOTA BCG (2003)**	**Higley & Kuperman / RESRAD-BIOTA**	**Limiting Organism**
Americium-241	4.60E+04	5.15E+03	8.93E+00	Riparian Animal
Cesium-137	4.80E+03	3.12E+03	1.54E+00	Riparian Animal
Hydrogen-3	3.50E+05	3.74E+05	9.36E-01	Riparian Animal
Plutonium-238	5.00E+04			
Plutonium-239	5.20E+05	5.86E+03	8.87E+01	Riparian Animal
Radium-226	3.80E+05	1.01E+02	3.76E+03	Riparian Animal
Radium-228	2.50E+05	8.78E+01	2.85E+03	Riparian Animal
Strontium-89	6.70E+03			
Strontium-90	3.50E+03	5.82E+02	6.01E+00	Riparian Animal
Uranium-233/234	1.00E+04	5.28E+03	1.90E+00	Riparian Animal
Uranium-235	1.00E+04	3.73E+03	2.68E+00	Riparian Animal
Uranium-238	4.20E+03	2.49E+03	1.69E+00	Riparian Animal

The average ratio of limiting concentrations for Higley and Kuperman vs. RESRAD-BIOTA for sediments is 672. Higley and Kuperman allows approximately 89 times higher concentrations of Pu-239 than does RESRAD-BIOTA. For H-3, the concentrations are nearly identical. For all other non-radium radionuclides in Table 4, Higley and Kuperman allow from 1.5 to 9 times higher concentrations. However, for the two radium isotopes, Higley and Kuperman are roughly 3000 times more "lenient" than RESRAD-BIOTA. These ratios are plotted in Fig. 3.

Fig. 3. Ratio of Limiting Concentrations in Sediment



SUMMARY

Within each medium, there is no clear trend in the data presented above. However, when comparing media to media, a trend does appear. For soil, the average Higley and Kuperman to RESRAD-BIOTA ratio is 1.55. For sediments, the ratio is 14 without the radium isotopes and 672 with the radium isotopes. For water, the average ratio of Higley and Kuperman vs. RESRAD-BIOTA is 248. Although there are exceptions for individual isotopes, the general conclusion is that the Higley and Kuperman concentrations tend to be higher than those calculated by RESRAD-BIOTA.

There is no obvious reason why the limiting concentrations of Higley and Kuperman vary from those used in RESRAD-BIOTA. There may be several reasons, including different values of concentration ratios, different elimination coefficients, and different dose coefficients. The DOE Standard has a more information about kinetic parameters, concentration ratios and dose coefficients than does the Higley and Kuperman document. It is unclear whether the data published in the standard is all used in RESRAD-BIOTA. The model's user's manual, will likely be helpful in ascertaining the differences when it published later this year/

According to ChemRisk (1991) the radionuclides of concern at Rocky Flats include Am-241, Pu-238, 239, 240, 241 and -242, Th-232, U-233, 245, 235, and -238, and tritium. The Phase I study (ChemRisk, 1994) identified Pu as the primary material of concern with respect to off-site exposures. Of the five plutonium isotopes listed above, Pu-239/240 supply over 97% of the alpha activity. Therefore, it seems reasonable from the standpoint of limiting risk to wildlife to consider Pu-239/240 as being more important than other radionuclides examined above. With that in mind, the limiting concentrations of Higley and Kuperman (1995) for soil, water, and sediment are 0.62, 5.4, and 89, respectively, relative to RESRAD-BIOTA level 1 biota concentration guidelines. This means that the earlier study allowed less Pu-239/240 in soils than RESRAD-BIOTA, but more Pu-239/240 in water and sediment.

In absolute terms, the trend towards higher limiting concentrations published in Higley and Kuperman (1995) might seem to be significant, but there are a wide variety of uncertainties that probably make the differences less important. Among these are the lumping together of various types of organisms into groups such as "terrestrial animal." For example, there would be a large disparity between the potential exposure scenarios of mule deer and deer mouse, but they are both considered terrestrial animals. Within the same general group, reptiles are more radioresistant, given the same exposures. Further, actual specification of contaminated areas, with statistically planned sampling would undoubtedly lead to better estimates of concentrations.

For other reasons, the risks to biota are relatively minor at Rocky Flats, no matter what the relationship between limiting factors of the two studies. As stated by Clarke and Holm (2003), "...the standards of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk." ICRP Publication 60 (1990) amplifies this statement:

> "The Commission believes that the standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk. Occasionally, individual members of non-human species might be harmed, but not to the extent of endangering whole species or creating imbalance between species."

In a similar vein, the International Atomic Energy Agency (IAEA, 1992) concluded, among other things, that

> "calculations of dose to natural organisms are thought to be conservative by 1-2 orders of magnitude. For these reasons, the chronic dose rate to animals and plants should be substantially less than 1 mGy•day $^{-1}$ under prevailing radiation protection standards."

The gist of these quotes is that if human beings are protected by limiting concentrations in environmental media, then aquatic and terrestrial animals and terrestrial plants will likewise be protected. For example, the Tier II soil action level for ^{239}Pu of 252 pCi/g, as published in the Rocky Flats Cleanup Agreement, for the hypothetical resident is considerably lower that the BCG for ^{239}Pu (Table 2). Higley and Kuperman (1995) and RESRAD-BIOTA have limiting factors of 3800 and 6110 pCi/g, respectively, to protect terrestrial animals from ^{239}Pu in soil. It is important to note that the presumed level of protection for the human, 15 mrem/yr, is considerably greater than for the terrestrial animal, 0.1 mrad/d. However given the proximity of the Rocky Flats site to suburban

Denver, it appears that concentrations in soil and water that meet public radiation protection standards would be highly protective of biota on the site.

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Table B.4
Sediment ESLs Aquatic Receptors
Rocky Flats Envoronmental Technology Site

ECOI	Low ESL (mg/kg)	High ESL (mg/kg)	Source Low ESL	Source High ESL	Surrogate Used
1,1,1-Trichloroethane	0.00119	0.00477	CCME (1999)		
1,1,2,2-Tetrachloroethane	0.0022	1.6	MacDonald et al. (1999)	MacDonald et al. (1999)	
1,1-Dichloroethene	0.00354	0.00851	CCME (1999)	CCME (1999)	
1,2,4-Trichlorobenzene	No Value Available				
1,2-Dichloroethane	No Value Available				
1,2-Dichloroethene (total)	No Value Available				
2-Butanone	No Value Available				
2-Methylnaphthalene	0.0202	0.201	CCME (1999)	CCME (1999)	
2-Methylphenol (o-cresol)	0.89	2.5	MacDonald et al. (1999)	MacDonald et al. (1999)	Toluene used as a surrogate
4,4-DDD	0.00354	0.06	NOAA (1999)	NOAA (1999)	
4,4-DDE	0.00142	0.05	NOAA (1999)	NOAA (1999)	
4,4-DDT	0.05	0.71	MacDonald et al. (2000b)	MacDonald et al. (2000b)	
4-Isopropyltoluene	No Value Available				
4-Methyl-2-pentanone	No Value Available				
4-Methylphenol (p-cresol)	0.89	2.5	MacDonald et al. (1999)	MacDonald et al. (1999)	Toluene used as a surrogate
Acenaphthene	0.00671	0.0889	CCME (1999)	CCME (1999)	
Acenaphthylene	0.00587	0.128	CCME (1999)	CCME (1999)	
Acetone	No Value Available				
Aldrin	0.0006	0.08	MacDonald et al. (1999)	MacDonald et al. (1999)	
alpha-BHC	No Value Available				
alpha-Chlordane	No Value Available				
Aluminum	15.9	58	TNRCC 1996	Ingersoll et al. 1996	
Anthracene	0.0469	3.7	CCME (1999)	MacDonald et al. (2000b)	
Antimony	2	0.07	MacDonald et al. (1999)	MacDonald et al. (1999)	
Polyclorinated Biphenyls (Total)	0.048	1.7	MacDonald et al. (2000c)	MacDonald et al. (2000c)	
Arsenic	5.9	17	CCME (1999)	CCME (1999)	
Barium	20	0.287	MacDonald et al. (1999)	MacDonald et al. (1999)	
Benzene	0.008	0.34	MacDonald et al. (1999)	MacDonald et al. (1999)	
Benzo(a)anthracene	0.0317	0.5	NOAA (1999)	NOAA (1999)	
Benzo(a)pyrene	0.0319	0.7	NOAA (1999)	NOAA (1999)	
Benzo(b)fluoranthene	0.0319	0.7	NOAA (1999)	NOAA (1999)	Benzo(a)pyrene used as a surrogate
Benzo(g,h,i)perylene	0.0104	3.2	MacDonald et al. (1999)	MacDonald et al. (1999)	
Benzo(k)fluoranthene	0.0026	13.4	MacDonald et al. (1999)	MacDonald et al. (1999)	
Benzoic Acid	No Value Available				
Benzyl Alcohol	No Value Available				
Beryllium	No Value Available				
beta-BHC	No Value Available				
beta-Chlordane	No Value Available				
bis(2-chloroisopropyl)ether	No Value Available				
bis(2-ethylhexyl)phthalate	0.01995	0.75	MacDonald et al. (1999)	MacDonald et al. (1999)	
Bromomethane (methyl bromide)	No Value Available				
Butylbenzylphthalate	11	500	MacDonald et al. (1999)	MacDonald et al. (1999)	
Cadmium	0.6	3.5		CCME (1999)	
Carbazole	0.14	1.8	MacDonald et al. (1999)	MacDonald et al. (1999)	
Carbon tetrachloride	0.044	1.2	MacDonald et al. (1999)	MacDonald et al. (1999)	
Chloroform	0.0004	NV	MacDonald et al. (1999)	NA	
Chromium III	37.3	90	CCME (1999)	CCME (1999)	
Chromium VI	37.3	90	CCME (1999)	CCME (1999)	Chromium III used as a surrogate
Chrysene	0.0571	0.862	CCME (1999)	CCME (1999)	
Cobalt	NV	50	NA	MacDonald et al. (1999)	
Copper	35.7	86	CCME (1999)	NOAA (1999)	
Dibenz(a,h)anthracene	0.00622	0.135	CCME (1999)	CCME (1999)	
Dibenzofuran	2	5.1	MacDonald et al. (1999)	NOAA (1999)	
Diethylphthalate	0.32	0.63	MacDonald et al. (1999)	MacDonald et al. (1999)	
Dimethylphthalate	0.32	0.63	MacDonald et al. (1999)	MacDonald et al. (1999)	Diethyphthalate used as a surrogate
Di-n-butylphthalate	0.042	0.043	MacDonald et al. (1999)	MacDonald et al. (1999)	
Di-n-octylphthalate	0.042	0.043	MacDonald et al. (1999)	MacDonald et al. (1999)	Di-n-butylphthalate used as a surrogate
Endosulfan I	0.0003	0.0078	MacDonald et al. (1999)	MacDonald et al. (1999)	
Fluoranthene	2.355	10.2	MacDonald et al. (2000b)	MacDonald et al. (2000b)	
Fluorene	0.0212	1.6	CCME (1999)	MacDonald et al. (2000b)	
Fluoride (as fluorine)	0.01	96	MacDonald et al. (1999)	MacDonald et al. (1999)	
gamma-BHC (Lindane)	0.00138	0.01	MacDonald et al. (2000b)	MacDonald et al. (2000b)	
Heptachlor	0.0003	0.01	MacDonald et al. (1999)	NOAA (1999)	
Heptachlor epoxide	0.00274	0.05	MacDonald et al. (2000b)	MacDonald et al. (2000b)	
Hexachlorobutadiene	0.004	0.55	MacDonald et al. (1999)	MacDonald et al. (1999)	
Indeno(1,2,3-cd)pyrene	0.0104	3.2	MacDonald et al. (1999)	MacDonald et al. (1999)	
Iron	20000	40000	MacDonald et al. (1999)	MacDonald et al. (1999)	
Lead	0.0913	0.25	MacDonald et al. (2000b)	MacDonald et al. (2000b)	
Lithium	No Value Available				
Manganese	300	1200	MacDonald et al. (1999)	MacDonald et al. (1999)	
Mercury	0.000486	0.002	MacDonald et al. (2000b)	MacDonald et al. (2000b)	
Methoxychlor	0.006	0.019	MacDonald et al. (1999)	MacDonald et al. (1999)	
Methylene chloride	0.5		MacDonald et al. (1999)		
Molybdenum	No Value Available				
Naphthalene	0.0346	0.391	CCME (1999)	CCME (1999)	
Nickel	0.036	0.075	MacDonald et al. (2000b)	MacDonald et al. (2000b)	
Nitrate	No Value Available				
Nitrite	No Value Available				
Pentachlorophenol	0.04	NV	MacDonald et al. (1999)	NA	
Phenanthrene	0.0419	0.515	CCME (1999)	CCME (1999)	
Phenol	0.00106	0.048	MacDonald et al. (1999)	MacDonald et al. (1999)	
Pyrene	0.875	8.5	MacDonald et al. (2000b)	MacDonald et al. (2000b)	

Table B.4
Sediment ESLs Aquatic Receptors
Rocky Flats Envoronmental Technology Site

ECOI	Low ESL (mg/kg)	High ESL (mg/kg)	Source Low ESL	Source High ESL	Surrogate Used
Selenium	0.00095	0.00173	MacDonald et al. (1999)	MacDonald et al. (1999)	
Silver	1	3.7	Long et al. 1995	Long et al. 1995	
Strontium	No Value Available				
Tetrachloroethene	0.0022	1.6	MacDonald et al. (1999)	MacDonald et al. (1999)	
Thallium	No Value Available				
Tin	No Value Available				
Toluene	0.89	2.5	MacDonald et al. (1999)	MacDonald et al. (1999)	
Trichloroethene	0.0001	2.1	MacDonald et al. (1999)	MacDonald et al. (1999)	
Trichlorofluoromethane	No Value Available				
Uranium (Total)	No Value Available				
Vanadium	No Value Available				
Vinyl chloride	No Value Available				
Xylene (total)	No Value Available				
Zinc	0.315	0.82	MacDonald et al. (2000b)	MacDonald et al. (2000b)	

NOTE: Only ECOIs detected in sediments are listed in Table 3.

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Long et al. (1995): Long, E., D. Macdonald, S. Smith, F. Calder. 1995. Incidence of adverse biological effects within ranges of chemical *concentrations in marine and estuary sediments.* Environ. Mgmt. 19:81-97.
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MacDonald et al. (2000a): Macdonald et al. 2000. A compendium of environmental quality benchmarks. prepared for Environment Canada)
MacDonald et al. (2000b): MacDonald, D.D., C.G. Ingersoll., T.A. Berger. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Arch. Environ. Contam. Toxicol. 39:20-31).

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Table B-5
Surface Water ESLs For Aquatic Receptors

ECOI	Acute (ug/L)	Chronic (ug/L)	Type of Benchmark (AWQC, Tier II, etc.)	Source Benchmark	Notes.
1,1,1-Trichloroethane	800	89	Tier II	MIDEQ 2003	
1,1,2,2-Tetrachloroethane	NV	2400	AWQC	CDPHE 2002	
1,1,2-Trichloroethane	NV	NV			
1,1-Dichloroethane	13000	740	Tier II	MIDEQ 2003	
1,1-Dichloroethene	NV	NV			
1,1-Dichloroethylene	2300	65	Tier II	MIDEQ 2003	
1,2,4-Trichlorobenzene	NV	NV			
1,2-Dichloroethane	118000	20000	AWQC	CDPHE 2002	
1,2-Dichloroethylene (total)	9600	1100	Tier II	MIDEQ 2003	
1,2-Dichloropropane	NV	NV			
1,4-Dichlorobenzene	NV	NV			
2,4,5-Trichlorophenol	NV	NV			
2,4-Dichlorophenol	NV	NV			
2,4-Dimethylphenol	2120	212	AWQC	CDPHE 2002; Chronic value estimated	Chronic = Acute/10
2-Butanone	40000	21200	Tier II	CDPHE 2002	
2-Chloronaphthalene	NV	NV			
2-Methylnaphthalene	NV	NV			
2-Methylphenol	NV	NV			
4,4'-DDD	NV	NV			
4,4'-DDE	NV	NV			
4-Chloroaniline	NV	NV			
Cadmium	4.3	2.2	AWQC	EPA 2002	hardness dependent, 100 mg/L
Chromium III	570	74	AWQC	CDPHE 2002	hardness dependent, 100 mg/L
Copper	13	9	AWQC	CDPHE 2002	hardness dependent, 100 mg/L
Lead	65	2.5	AWQC	CDPHE 2002	hardness dependent, 100 mg/L
Manganese	2990	1650	AWQC	CDPHE 2002	hardness dependent, 100 mg/L
Nickel	470	52	AWQC	CDPHE 2002	hardness dependent, 100 mg/L
Silver	8	0.3	AWQC	CDPHE 2002	hardness dependent, 100 mg/L
Zinc	120	120	AWQC	CDPHE 2002	hardness dependent, 100 mg/L
4-Methyl-2-pentanone	NV	NV			
4-Methylphenol (p-cresol)	450	25	Tier II	MIDEQ 2003	
Acenaphthylene	1700	520	AWQC	CDPHE 2002	
Acetone	28000	1500	Tier II	DOE 1996	
Aldrin	NV	NV			
Barium	2498	438	Tier II	MIDEQ 2003	hardness dependent, 100 mg/L
alpha-BHC	39	2.2	Tier II	DOE 1996	BHC (other) value used.
Aluminum	750	87	AWQC	CDPHE 2002	
Americium-241	NV	NV			

Table B-5
Surface Water ESLs For Aquatic Receptors

ECOI	Acute (ug/L)	Chronic (ug/L)	Type of Benchmark (AWQC, Tier II, etc.)	Source Benchmark	Notes.
Ammonium (as Ammonia)	77 [1]	20	AWQC	CDPHE 2002	pH, temperature, life-stage dependent
Anthracene	NV	NV			
Antimony	2300	240	Tier II	MIDEQ 2003	
Aroclor-1016	NV	NV			
Beryllium	43	2.4	Tier II	MIDEQ 2003	hardness dependent, 100 mg/L
Arsenic	50	100	AWQC	CDPHE 2002	chronic = total recoverable; Segment specific value from Big Dry Creek Segment #5
Barium	3654	640	Tier II	MIDEQ 2003	hardness = 143 mg/L
Benzene	5300	530	AWQC	CDPHE 2002; Chronic value estimated	Chronic = Acute/10
Benzo(a)anthracene	NV	NV			
Benzo(a)pyrene	NV	NV			
Benzo(b)fluoranthene	NV	NV			
Benzo(k)fluoranthene	NV	NV			
Benzoic Acid	NV	NV			
Beryllium	106	5.9	Tier II	MIDEQ 2003	hardness = 143 mg/L
beta-BHC	39	2.2	Tier II	DOE 1996	BHC (other) value used.
bis(2-ethylhexyl)phthalate	285	28.5	Tier II	MIDEQ 2003	Chronic = Acute/10
Bromodichloromethane	11000	NV	AWQC	CDPHE 2002	
Bromoform	NV	NV			
Bromomethane	NV	NV			
Butylbenzylphthalate	630	67	Tier II	MIDEQ 2003	
Cadmium	6.3	2.9	AWQC	EPA 2002	hardness = 143 mg/L
Carbon Disulfide	NV	NV			
Carbon tetrachloride	35200	3520	AWQC	CDPHE 2002; Chronic value estimated	Chronic = Acute/10
Chlorobenzene	NV	NV			
Chloroethane (ethyl chloride)	NV	NV			
Chloroform	28900	1240	AWQC	CDPHE 2002	
Chloromethane (methyl chloride)	55000	5500	AWQC	UESPA 2001	Chronic = Acute/10
Chromium III	763	99	AWQC	CDPHE 2002	hardness = 143 mg/L
Chrysene	NV	NV			
cis-1,2-Dichloroethene	11000	620	Tier II	MIDEQ 2003	
Cobalt	740	100	Tier II	MIDEQ 2003	
Copper	19	12	AWQC	CDPHE 2002	hardness = 143 mg/L
Cyanide	0.5	5	AWQC	CDPHE 2002; Chronic value estimated	Chronic = Acute/10; Expressed as free cyanide
Dibenzofuran	72	4	Tier II	MIDEQ 2003	
Dibromochloromethane	NV	NV			
Dieldrin	NV	NV			

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Table B-5
Surface Water ESLs For Aquatic Receptors

ECOI	Acute (ug/L)	Chronic (ug/L)	Type of Benchmark (AWQC, Tier II, etc.)	Source Benchmark	Notes
Diethylphthalate	2000	110	Tier II	MIDEQ 2003	
Dimethylphthalate	NV	NV			
Di-n-butylphthalate	75	9.7	Tier II	MIDEQ 2003	
Di-n-octylphthalate	NV	NV			
Ethylbenzene	32000	3200	AWQC	CDPHE 2002; Chronic value estimated	Chronic = Acute/10
Fluoranthene	NV	NV			
Fluorene	220	12	Tier II	MIDEQ 2003	
Fluoride (as fluorine)	10200	2120	Tier II	NY State 1998	
gamma-BHC (Lindane)	0.95	0.08	AWQC	CDPHE 2002	
Heptachlor	0.52	0.0038	AWQC	CDPHE 2002	
Hexachlorobutadiene	NV	NV			
Hexachloroethane	NV	NV			
Indeno(1,2,3-cd)pyrene	NV	NV			
Iron	NV	1000	AWQC	CDPHE 2002	
Isophorone	NV	NV			
Lead	95	3.7	AWQC	CDPHE 2002	hardness = 143 mg/L
Lithium	1700	96	Tier II	MIDEQ 2003	
Manganese	3360	1860	AWQC	CDPHE 2002	hardness = 143 mg/L
Mercury	1.4	0.77	AWQC	CDPHE 2002	
Methylene chloride	17000	940	Tier II	MIDEQ 2003	
Molybdenum	14000	800	Tier II	MIDEQ 2003	
Naphthalene	2300	620	AWQC	CDPHE 2002	
Nickel	630	70	AWQC	CDPHE 2002	hardness = 143 mg/L
Nitrate	NV	10000	AWQC	CDPHE 2002	
Nitrite	NV	4500	AWQC	CDPHE 2002	
Pentachlorophenol	NV	NV			
Phenanthrene	43	2.4	Tier II	MIDEQ 2003	
Phenol	10200	2560	AWQC	CDHPE 2002	
Pyrene	NV	0.025	CWQ	CCME 2002	
Selenium	18.4	4.6	AWQC	CDPHE 2002	
Silver	15	0.6	AWQC	CDPHE 2002	hardness = 143 mg/L
Strontium	150000	8300	Tier II	MIDEQ 2003	
Styrene	NV	NV			
Tetrachloroethene	5280	840	AWQC	CDPHE 2002	
Thallium	160	15	Tier II/AWQC	MIDEQ 2003/CDPHE 2002	
Tin	2700	73	Tier II	DOE 1996	

Table B-5
Surface Water ESLs For Aquatic Receptors

ECOI	Acute (ug/L)	Chronic (ug/L)	Type of Benchmark (AWQC, Tier II, etc.)	Source Benchmark	Notes.
Toluene	17500	1750	CDPHE 2002; Chronic value estimated	Chronic = Acute/10	
trans-1,3-Dichloropropene	NV	NV			
Trichloroethene	45000	21900	AWQC	CDPHE 2002	
Trichlorofluoromethane	NV	NV			
Uranium (total)	46.5	2.6	Tier II	DOE 1996	
Vanadium	220	12	Tier II	MIDEQ 2003	
Vinyl chloride	17000	930	Tier II	MIDEQ 2003	
Xylene (total)	630	35	Tier II	MIDEQ 2003	
Zinc	160	160	AWQC	CDPHE 2002	hardness = 143 mg/L

Citations by priority

1) CDPHE 2002 (Colorado Department of Public Health and Environment; Regulation No. 38 Classifications and Numeric Standards South Platte River Basin)
2) USEPA 2002 (National Recommended Water Quality Criteria, November 2002)
3) MIDEQ 2003. (Rule 57 Water Quality Values; Department of Environmental Quality, February 2003)
4) CCME 2002. (Canadian Environmental Quality Guidelines; Canadian Council of Ministers of the Environment)
5) DOE 1996 (Suter and Tsao Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effect on Aquatic biota)
6) NY State 1998 (Ambient Water Quality Standards and Guidance Values and Groundwater Effluent Limitations, June 1998)
7) USEPA 1999 (Update of Ambient Water Quality Criteria for Ammonia, September 1999)

[1] The acute value for ammonium was calculated using the following assumptions: water temperature = 20^0 C, pH = 7.0. The equation for calculating this value is: 0.43/FT/FPH/2

Table B.6
ESLs For Terrestrial Plants and Invertebrates
Rocky Flats Environmental Technology Site

ECOI	Soil Invertebrate (mg/kg)	Terrestrial Plant (mg/kg)	MOEE 1996 (ONTARIO) Plants and Invertebrates (mg/kg)	Invert Source	Plant Source
1,1,1-Trichloroethane	NV	NV	26		
1,1,2,2-Tetrachloroethane	NV	NV			
1,1,2-Trichloroethane	NV	NV	0.28		
1,1-Dichloroethane	NV	NV	3		
1,1-Dichloroethene	NV	NV	0.0024		
1,2,4,5-Tetrachlorobenzene	10	NV		Efroymson et al. 1997a	
1,2,4-Trichlorobenzene	20	NV	30	Efroymson et al. 1997a	
1,2-Dichlorobenzene (o-)	NV	NV	0.88		
1,2-Dichloroethane	NV	NV	0.022		
1,2-Dichloroethene (total)	NV	NV	4.1		
1,2-Dichloropropane	700	NV	0.019	Efroymson et al. 1997a	
1,2-Dimethylbenzene	NV	NV			
1,4-Dichlorobenzene (p-)	20	NV	0.32	Efroymson et al. 1997a	
1-methyl napthalene	NV	NV			
2,3,7,8-tetrachlorodibenzo-p-dioxin	NV	NV			
2,4,5-Trichlorophenol	9	4	3.2	Efroymson et al. 1997a	Efroymson et al. 1997b
2,4,6-Trichlorophenol	10	4	0.66	Efroymson et al. 1997a	Efroymson et al. 1997b
2,4-Dichlorophenol	20	20	0.3	Efroymson et al. 1997a	Efroymson et al. 1997b
2,4-Dimethylphenol	NV	NV	0.94		
2,4-Dinitrophenol	NV	20	0.2	Efroymson et al. 1997a	Efroymson et al. 1997b
2,4-Dinitrotoluene	NV	NV	0.66		
2,6-Dinitrotoluene	NV	NV			
2-Butanone	NV	NV			
2-Chloronaphthalene	NV	NV			
2-Chlorophenol	10	7	0.1	Efroymson et al. 1997a	Efroymson et al. 1997b
2-Methylnaphthalene	NV	NV			
2-Methylphenol (o-cresol)	NV	NV			
2-Nitroaniline	NV	NV			
3,3-Dichlorobenzidine	NV	NV	1.3		
4,4-DDD	NV	NV	2.2		
4,4-DDE	NV	NV	1.6		
4,4-DDT	NV	NV	1.6		
4,6-Dinitro-2-methylphenol	NV	NV			
4-Bromophenyl phenyl ether	NV	NV			
4-Chloroaniline	30	20		Efroymson et al. 1997a	Efroymson et al. 1997b
4-isopropyltoluene	NV	NV			
4-Methyl-2-pentanone	NV	NV			
4-Methylphenol (p-cresol)	NV	NV			
4-Nitrophenol	7	NV		Efroymson et al. 1997a	
Acenaphthene	NV	20	15		Efroymson et al. 1997b
Acenaphthylene	NV	NV	100		
Acetone	NV	NV	3.5		
Aldrin	NV	NV	0.05		
alpha-BHC	NV	NV			
alpha-Chlordane	NV	NV			
Aluminum	NV	50			Efroymson et al. 1997b
Ammonium (as Ammonia)	NV	NV			
Anthracene	NV	NV	28		
Antimony	78	5	13	USEPA, 2003	Efroymson et al. 1997b
Aroclor 1016	NV	40 (PCBs)			Efroymson et al. 1997b
Aroclor 1221	NV	40 (PCBs)			Efroymson et al. 1997b
Aroclor 1232	NV	40 (PCBs)			Efroymson et al. 1997b
Aroclor 1242	NV	40 (PCBs)			Efroymson et al. 1997b
Aroclor 1248	NV	40 (PCBs)			Efroymson et al. 1997b
Aroclor 1254	NV	40 (PCBs)			Efroymson et al. 1997b
Aroclor 1260	NV	40 (PCBs)			Efroymson et al. 1997b
Arsenic	60	10	20	Efroymson et al. 1997a	Efroymson et al. 1997b
Barium	330	500	750	USEPA, 2003	Efroymson et al. 1997b
Benzene	NV	0.5	0.24		CCME, 1999
Benzene, 1,2,4-Trimethyl	NV	NV			
Benzene, 1,3,5-Trimethyl	NV	NV			
Benzo(a)anthracene	NV	NV	6.6		
Benzo(a)pyrene	NV	NV	1.2		
Benzo(b)fluoranthene	NV	NV	12		
Benzo(g,h,i)perylene	NV	NV	40		
Benzo(k)fluoranthene	NV	NV	12		
Benzoic Acid	NV	NV			

Table B.6
ESLs For Terrestrial Plants and Invertebrates
Rocky Flats Environmental Technology Site

ECOI	Soil Invertebrate (mg/kg)	Terrestrial Plant (mg/kg)	MOEE 1996 (ONTARIO) Plants and Invertebrates (mg/kg)	Invert Source	Plant Source
Benzyl Alcohol	NV	NV			
Beryllium	40	10	1.2	USEPA, 2003	Efroymson et al. 1997b
beta-BHC	NV	NV			
beta-Chlordane	NV	NV			
bis(2-chloroethyl)ether	NV	NV	0.66		
bis(2-chloroisopropyl)ether	NV	NV	0.66		
bis(2-ethylhexyl)phthalate	NV	NV	100		
Boron	NV	0.5	1.5		Efroymson et al. 1997b
Bromodichloromethane	NV	NV	0.12		
Bromoform	NV	NV	0.11		
Bromomethane (methyl bromide)	NV	NV	0.061		
Butylbenzylphthalate	NV	NV			
Cadmium	140	32	12	USEPA, 2003	USEPA, 2003
Carbazole	NV	NV			
Carbon disulfide	NV	NV			
Carbon tetrachloride	NV	NV	0.1		
Chlorobenzene	40	NV	2.4	Efroymson et al. 1997a	
Chloroethane (ethyl chloride)	NV	NV			
Chloroform	NV	NV	0.13		
Chloromethane (methyl chloride)	NV	NV			
Chromium	0.4	1		Efroymson et al. 1997a	Efroymson et al. 1997b
Chromium III	NV	NV	8		
Chromium VI	NV	NV	12		
Chrysene	NV	NV			
cis-1,3-Dichloropropene	NV	NV	40		
Cobalt	NV	13	225		USEPA, 2003
Copper	50	100	100	Efroymson et al. 1997a	Efroymson et al. 1997b
Cyanide	NV	NV	1.2		
Dibenz(a,h)anthracene	NV	NV			
Dibenzofuran	NV	NV	0.09		
Dibromochloromethane	NV	NV	0.05		
Dieldrin	NV	NV	0.71		
Diethylphthalate	NV	100	0.7		Efroymson et al. 1997b
Dimethylphthalate	200	NV		Efroymson et al. 1997a	
Di-n-butylphthalate	NV	200			Efroymson et al. 1997b
Di-n-octylphthalate	NV	NV	0.18		
Endosulfan (technical)	NV	NV			
Endosulfan I	NV	NV			
Endosulfan II	NV	NV			
Endosulfan sulfate	NV	NV	0.05		
Endrin	NV	NV	0.28		
Ethylbenzene	NV	NV	40		
Fluoranthene	NV	NV	340		
Fluorene	30	200		Efroymson et al. 1997a	Efroymson et al. 1997b
Fluoride (as fluorine)	NV	NV	1.0 ng TEQ/g soil		
Furan	NV	600			Efroymson et al. 1997b
gamma-BHC (Lindane)	NV	NV			
gamma-Chlordane	NV	NV	0.084		
Heptachlor	NV	NV	0.06		
Heptachlor epoxide	NV	NV	0.46		
Hexachlorobenzene	NV	NV	0.38		
Hexachlorobutadiene	NV	NV	0.41		
Hexachlorocyclohexane, gamma	NV	NV			
Hexachlorocyclopentadiene	NV	10	3.8		Efroymson et al. 1997b
Hexachloroethane	NV	NV	12		
Indeno(1,2,3-cd)pyrene	NV	NV			
Iron	NV	10 in solution			Efroymson et al. 1997b
Isophorone	NV	NV	200		
Lead	1700	110		USEPA, 2003	USEPA, 2003
Lithium	NV	2			Efroymson et al. 1997b
Manganese	NV	500	10		Efroymson et al. 1997b
Mercury	0.1	0.3	4	Efroymson et al. 1997a	Efroymson et al. 1997b
Methoxychlor	NV	NV	1.1		
Methylene chloride	NV	NV	40		

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Table B.6
ESLs For Terrestrial Plants and Invertebrates
Rocky Flats Environmental Technology Site

ECOI	Soil Invertebrate (mg/kg)	Terrestrial Plant (mg/kg)	MOEE 1996 (ONTARIO) Plants and Invertebrates (mg/kg)	Invert Source	Plant Source
Molybdenum	NV	2	4.6		Efroymson et al. 1997b
Naphthalene	NV	NV	150		
Nickel	200	30		Efroymson et al. 1997a	Efroymson et al. 1997b
Nitrate	NV	NV			
Nitrite	NV	NV			
Nitrobenzene	40	NV		Efroymson et al. 1997a	
n-Nitrosodiphenylamine	20	NV		Efroymson et al. 1997a	
n-Nitrosodipropylamine	NV	NV			
Pendimethalin	NV	NV			
Pentachlorobenzene	20	NV		Efroymson et al. 1997a	
Pentachloronitrobenzene	NV	NV	5		
Pentachlorophenol	6	3	40	Efroymson et al. 1997a	Efroymson et al. 1997b
Phenanthrene	NV	NV	40		
Phenol	30	70	250	Efroymson et al. 1997a	Efroymson et al. 1997b
Pyrene	NV	NV	10		
Selenium	70	1	20	Efroymson et al. 1997a	Efroymson et al. 1997b
Silver	NV	2			Efroymson et al. 1997b
Strontium	NV	NV	1.2		
Styrene	NV	300	0.45		Efroymson et al. 1997b
Tetrachloroethene	NV	NV	4.1		
Thallium	NV	1			Efroymson et al. 1997b
Tin	NV	50			Efroymson et al. 1997b
Titanium	NV	0.06 in solution	2.1		Efroymson et al. 1997b
Toluene	NV	200			Efroymson et al. 1997b
Toxaphene	NV	NV			
trans-1,3-Dichloropropene	NV	NV	1.1		
Trichloroethene	NV	NV			
Trichlorofluoromethane	NV	NV			
Trifluralin	NV	NV			
Uranium (Total)	NV	5	200		Efroymson et al. 1997b
Vanadium	NV	2			Efroymson et al. 1997b
Vinyl acetate	NV	NV	0.003		
Vinyl chloride	NV	NV	25		
Xylene (total)	NV	NV	600		
Zinc	200	50		Efroymson et al. 1997a	Efroymson et al. 1997b

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